1   Appendix 5.F
2   **Biological Stressors on Covered Fish**

3

Biological Stressors on Covered Fish

5.F.0   Executive Summary

5.F.0.1   Aquatic Biological Stressors and the BDCP

Biological stresses can result from competition, herbivory, predation, parasitism, toxins, and disease. In addition to habitat alteration, the introduction of invasive species is one of the most prevalent causes of biological stress for the Bay Delta Conservation Plan (BDCP) covered fish in the Sacramento–San Joaquin River Delta (Delta). More than 250 nonnative aquatic and plant species have been introduced into the Delta (Cohen and Carlton 1995). Of these, at least 185 species have become established and altered the Delta's ecosystem. Current estimates suggest that more than 95% of the biomass in the Delta is composed of nonnative species. These introduced invasive species, along with other changes to the Delta, have contributed to conditions that resulted in the current status of covered fish species (Chapter 3, *Conservation Strategy*). Factors that either directly or indirectly cause biological stress for covered fish species include invasive aquatic vegetation (IAV), predation, invasive mollusks, and *Microcystis*. The conservation measures address a wide spectrum of aquatic and terrestrial environmental stressors across the Plan Area. Reducing the negative effects of key biological stressors is an important component of meeting goals and objectives for covered fish species (Chapter 3, *Conservation Strategy*). This appendix examines the effects of implementation of the 10 conservation measures that address or are affected by four key biological stressors:

- IAV
- Predation
- Invasive mollusks
- *Microcystis*

These biological stressors have been identified as potential mechanisms that resulted in the current status of the covered fish as well as potential deterrents to recovery. As such, these stressors were given specific attention in this appendix.

5.F.0.2   Summary of Conclusions

5.F.0.2.1   Invasive Aquatic Vegetation

The control of invasive submerged aquatic vegetation (*CM13 Invasive Aquatic Vegetation Control*) should reduce local predation mortality of covered fish species by removing habitat for predators and increasing turbidity locally.

IAV control should benefit covered fish species that use shallow-water habitats (habitats prone to IAV growth) like salmonids and splittail, but should have a minor beneficial effect on pelagic fishes like delta smelt and longfin smelt. Control of IAV, especially Brazilian waterweed (*Egeria densa*), is expected to enhance natural ecosystem functions by removing ecologically dominant species that

1   provide habitat and cover for nonnative predatory fish such as largemouth bass. Predation on
2   juvenile salmon, steelhead, and splittail in the migration corridor can be significant; for example,
3   juvenile Chinook salmon experience predation by largemouth bass lurking in invasive submerged
4   aquatic vegetation (SAV). Controlling IAV is expected to locally reduce densities of largemouth bass,
5   but conversely could enhance open water conditions favored by pelagic predators such as striped
6   bass.

7   Turbid conditions are important for delta smelt migration, spawning, and cover, but turbidity in the
8   Delta is lower than it was 30 to 40 years ago. Dense stands of IAV can reduce turbidity locally by
9   filtering sediment from the water and preventing resuspension (Hestir et al. 2010b). IAV control
10 would help maintain turbidity in restored habitats and potentially contribute to increased turbidity
11 in adjacent habitats invaded by *Egeria.* IAV removal alone would be insufficient to restore Delta-
12 wide turbidity to former levels because of overall reductions in sediment supply. Local increases in
13 turbidity potentially could improve conditions for delta smelt by improving concealment from visual
14 predators like largemouth bass and striped bass. The degree of benefit is uncertain and depends
15 both on the magnitude of turbidity increase and on how much control predation by these species
16 exerts on delta smelt population.

17 **The control of invasive aquatic vegetation (CM13) should increase food consumption by**
18 **covered fish species.**

19 Food consumption by delta smelt and longfin smelt larvae and juveniles is expected to increase if the
20 increased turbidity that would result from removing or reducing invasive SAV was a long-term
21 effect that reached the thresholds required to change the behavior of smelt. A certain concentration
22 of suspended particles seems to be necessary for proper feeding in young delta smelt—the larvae do
23 not feed in water that is too clear. The role and importance of turbidity for longfin smelt feeding
24 efficiency are not as well-known as they are for delta smelt. Understanding of the amount of overlap
25 between invasive SAV treatment areas and delta smelt and longfin smelt food areas is improving,
26 but overlap may be low for longfin smelt. However, it is known that areas currently occupied by
27 invasive SAV are not suitable for delta smelt; therefore, removal of invasive SAV may help to restore
28 and maintain suitable habitat conditions in restored areas.

29 In addition to facilitating feeding by delta smelt and longfin smelt, removal of dense stands of IAV
30 has the potential to increase availability of pelagic food (phytoplankton, zooplankton) near
31 treatment locations by increasing light levels below vegetation. Dense IAV blocks light penetration
32 into the water column. IAV control allows greater light penetration in the water column, leading to
33 greater phytoplankton productivity, which in turn leads to greater productivity of zooplankton that
34 constitute prey for a variety of covered fish species, primarily smelts and juvenile salmonids. Dense
35 IAV canopies reduce light penetration through the water column more than would the anticipated
36 increases in water turbidity resulting from IAV removal, and, as a result, it is anticipated that IAV
37 removal would lead to an increase in phytoplankton productivity. Additionally, control of IAV and
38 the restoration of native aquatic plant communities in treated areas are expected to increase the
39 quantity and value of habitat suitable for some prey resources (such as crustaceans, annelids,
40 mollusks, fish, and midges) important to green and white sturgeon. SAV removal and control thus
41 would lead to a net increase in food availability for these covered fish species.

1 **The control of invasive submerged aquatic vegetation (CM13) should increase the amount of**
2 **spawning and rearing habitat for covered fish species.**

3 Dense patches of invasive SAV physically obstruct covered fish species' access to habitat for
4 spawning and rearing. Removal of invasive SAV is expected to increase the availability of freshwater
5 spawning habitat for longfin smelt in the Delta (spawning occurs where average water temperatures
6 are 10 to 12 degrees Celsius (°C) from mid-December to April). There is no indication, however, that
7 the delta smelt population is limited by the amount of suitable spawning habitat area because they
8 spawn throughout the Delta in different years. Removal of dense stands of *Egeria* from channel edge
9 and shallow-water habitats is expected to increase the amount of suitable rearing and migration
10 habitat for juvenile salmonids and splittail.

5.F.0.2.2 Fish Predation

12 **Implementation of *CM1 Water Facilities and Operation* would decrease predation on covered fish**
13 **at the south Delta facilities. Increased predation will likely occur at the north Delta intake facility,**
14 **although the extent of the increase is uncertain.**

15 At the south Delta Central Valley Project (CVP) and State Water Project (SWP) facilities, losses
16 attributed to predation are an estimated 75% for salmonids in the SWP Clifton Court Forebay (CCF),
17 15% for salmonids at the CVP facilities, and more than 90% for delta smelt at CCF. Once the north
18 Delta facility is operating, reduced pumping at the south Delta facilities will result in substantially
19 reduced entrainment and, thus, reduced predation of covered fish species at these facilities.

20 The north Delta export facilities on the banks of the Sacramento River likely will attract piscivorous
21 fish around the intake structures. Predation losses at the intakes were estimated using striped bass
22 bioenergetics modeling of salmon and splittail predation, and a fixed 5% per intake assumed loss of
23 Chinook salmon smolts migrating past the facilities. While bioenergetics modeling predicted high
24 numbers of juvenile Chinook consumed (tens of thousands), the population level effect is minimal
25 (less than 1% of the annual Sacramento Valley production). The bioenergetics model likely
26 overestimates predation of juvenile salmon and splittail because of simplified model assumptions,
27 further indicating potential predation losses at the north Delta would be low.

28 The fixed 5% per intake loss assumption provides an upper bound of estimated losses at the north
29 Delta diversion. Of the Sacramento Basin population of Chinook salmon smolts that reach the Delta,
30 an estimated 3 to 10% (depending on the run) would migrate via the Yolo Bypass and would thus
31 avoid exposure to the north Delta intakes. An estimated 12.0 to 12.8% of the migrating smolt
32 population is assumed lost to predation, impingement, or injury as smolts emigrate past the three
33 north Delta diversion intakes. This loss assumption, based on the Glenn Colusa Irrigation District
34 (GCID) diversion, likely overestimates the mortality rates because the north Delta diversion design
35 and siting are considerably different.

36 These two methods provide a hypothetical range of potential mortality at the north Delta diversion,
37 from less than 1% to 12.8%, with uncertainties associated with each estimate. It should be noted
38 that the biological goals and objectives for salmonids (WRCS1, SRCS1, FRCS1, and STHD1) contain
39 survival rate targets in the new north Delta intakes reach (0.25-mile upstream of the upstream-most
40 intake to 0.25-mile downstream of the downstream-most intake) to 95% or more of the existing
41 survival rate in this reach. The reduction in survival of up to 5% below the existing survival rate
42 would be cumulative across all screens, and would not allow high levels of mortality at the new
43 intakes. The adaptive management program provides a mechanism for making adjustments to avoid

1   or minimize this effect. In addition, localized reduction of predatory fishes (Conservation Measure
2   [CM] 15) could provide a small beneficial effect. The Adaptive Management Team has primary
3   responsibility for administration of the adaptive management and monitoring program, including
4   development of performance measures, effectiveness monitoring, and research plans; analysis,
5   synthesis, and evaluation of monitoring and research results; soliciting independent scientific
6   review; and developing proposals to adapt (e.g., modify a conservation measure) as resource
7   conditions change and understanding evolves (Chapter 3, Section 3.6.2, *Structure of the Adaptive*
8   *Management Program*). The Implementation Office is responsible for providing technical and
9   logistical support to the Adaptive Management Team.

10 **Some of the benefits associated with implementation of habitat restoration measures (*CM2 Yolo***
11 ***Bypass Fisheries Enhancement, CM3 Natural Communities Protection and Restoration, CM4 Tidal***
12 ***Natural Communities Restoration, CM5 Seasonally Inundated Floodplain Restoration, CM6***
13 ***Channel Margin Enhancement, and CM7 Riparian Natural Community Restoration*) could be offset**
14 **by an increase in predation by largemouth bass and centrarchid fishes, if restored areas are**
15 **colonized by invasive aquatic vegetation; *CM13 Invasive Aquatic Vegetation Control,* and *CM15***
16 ***Localized Reduction of Predatory Fishes* should minimize this effect.**

17 If restored habitats become colonized by IAV, they could provide potential habitat for predatory
18 species. Consequently, predation risks would increase as largemouth bass become more prevalent in
19 those areas. Fish predators use seasonal wetlands, although warmwater species such as
20 centrarchids typically spawn later in the year when covered fish have already started to emigrate.
21 Habitat design and maintenance to discourage use of the restored areas, including removal of IAV,
22 should minimize this effect. Additionally, these restored areas may be targeted for predator removal
23 during key occurrence of covered species in these areas, which may also reduce this effect, although
24 outcomes of localized predator removal are uncertain.

25 ***CM15 Localized Reduction of Predatory Fishes* would reduce predation on covered fish species for**
26 **short periods in these areas, but outcomes are uncertain at the population scale.**

27 Predatory fishes such as striped bass and largemouth bass prey on covered fish species and can be
28 locally abundant at predation hotspots. Adult striped bass are pelagic predators that often
29 congregate near screened diversions, underwater structures, and salvage release sites to feed on
30 concentrations of small fish, especially salmon. Striped bass are a major cause of mortality of
31 juvenile salmon and steelhead near the SWP south Delta diversions (Clark et al. 2009). Largemouth
32 bass are nearshore predators associated with stands of IAV.

33 Targeted predator removal at hotspots, such as the north Delta diversion, would reduce local
34 predator abundance, thus reducing localized predation mortality of covered fish species. Predator
35 hotspots include submerged structures, scour holes, riprap, and pilings. Removal methods will
36 include electrofishing, gill netting, seining, and hook and line. Predator removal measures will be
37 highly localized and, thus, they would not appreciably decrease Delta-wide abundances of predatory
38 fish. Additionally, intensive removal efforts inadvertently could result in bycatch and take of covered
39 species in localized areas.

40 At the local scale, the benefits of targeted predator removal are likely to be localized spatially and of
41 short duration unless efforts are maintained over a long period of time. These benefits are highly
42 uncertain, as the long-term feasibility and effectiveness of localized predator reduction measures
43 are not known. Other control programs suggest that removal of predators even at a localized scale
44 will be difficult to achieve and maintain without a substantial level of effort. Highly mobile predators

1   like striped bass can recolonize targeted areas within a matter of days, implying that predator
2   removal will need to be conducted at frequent intervals when covered species are migrating.

3   At the population scale, the overall benefit for covered fishes is uncertain because localized predator
4   reduction measures may not capture sufficient predators to appreciably reduce mortality of covered
5   fishes. Also, there are uncertainties regarding causal relationships between Delta predators and
6   prey that make it difficult to predict the role of piscivorous fish in affecting the size of fish
7   populations Delta-wide (Durand 2008; Nobriga pers. comm.). A pilot program and research actions
8   proposed under *CM15 Localized Reduction of Predatory Fishes* will help address knowledge gaps
9   about effectiveness of predator removal techniques and the relative impact of top-down predation
10   on the population dynamics of covered fish species in the Delta.

11   ***CM16 Nonphysical Fish Barriers* could reduce fish predation by deterring covered fish from**
12   **predation hotspots. The underwater infrastructure may attract predatory fish, but predator**
13   **removal could help reduce predation risk.**

14   Nonphysical barriers at the head of Old River and at Georgiana Slough are designed to deter juvenile
15   salmonids from entering certain reaches of the Delta associated with poor survival. These barriers
16   operate by using strobe lights and speakers to deter juvenile fish, with a bubble curtain designed to
17   contain the noise and form a wall of sound. Salmon, steelhead, and splittail are expected to be
18   effectively deterred. Sturgeon and lamprey are not expected to be deterred by the presence of the
19   barriers. Delta smelt may be deterred to some extent, although weak swimming as young juveniles
20   decreases their ability to avoid the barriers. Longfin smelt are distributed too far west in the Delta to
21   encounter the nonphysical barriers. There may be a slight risk of predation related to the
22   underwater structures associated with nonphysical barriers that may attract fish predators. If
23   needed, targeted predator removal activities (CM15) would be implemented in these areas.

24   **Consolidation and screening of nonproject diversions (*CM21 Nonproject Diversions*) in the Delta**
25   **will have an unknown effect on fish predation.**

26   Much of the effect will depend on where in the Delta these nonproject diversions are, how and when
27   they are operated, the size and extent of submerged structure associated with them, and how they
28   will be modified. Installation of fish screens and other structures intended to reduce entrainment
29   losses of covered fish actually may attract additional predators and increase localized predation
30   risks. Consolidation would reduce the number of structures providing cover.

5.F.0.2.3   Invasive Mollusks

32   **Water operations (*CM1 Water Facilities and Operation*) may affect the average amount of habitat**
33   **with salinity greater than 2 parts per thousand (ppt) compared with existing biological conditions**
34   **with Fall X2 (EBC2), depending on the outcome of the Fall X2 decision tree, thus potentially**
35   **affecting suitable habitat for overbite clam (*Potamocorbula amurensis*).**

36   If Fall X2 is implemented, as is modeled in the evaluated starting operations (ESO), no change in
37   suitable habitat for *Potamocorbula* from water operations would occur. However, if Fall X2 is not
38   implemented, X2 would occur more easterly than under EBC2, and, therefore, the suitable habitat
39   for *Potamocorbula* recruitment would be expanded in wet and above normal water years. Likewise,
40   increased tidal habitat from restoration of tidal natural communities (CM4) may facilitate
41   recruitment and expansion of *Potamocorbula* if located in areas with salinity greater than 2 ppt. If
42   this occurs, the foodweb benefits described in Appendix 5.E, *Habitat Restoration*, may be reduced.

1   Water operations that affect salinity gradients could affect the recruitment and distribution of
2   *Potamocorbula* in the brackish western Delta and *Corbicula* in freshwater habitats. Water operations
3   (*CM1 Water Facilities and Operation*) for spring and fall outflow will be dictated by the decision tree
4   as described in Chapter 3, *Conservation Strategy*. The ESO includes the Fall X2 requirement.
5   Operations under the ESO generally provided *Potamocorbula* recruitment habitat suitability in the
6   West Delta and Suisun Bay subregions similar to the EBC2 scenarios, reflecting the inclusion of the
7   Fall X2 water management measure in CM1 during the main *Potamocorbula* recruitment period.
8   However, if Fall X2 is not implemented, operations would comply with State Water Resources
9   Control Board water right Decision 1641 (D-1641) Delta outflow requirements. In that situation,
10   outflows in wet and above normal years would be similar to EBC1, in which X2 is more east than
11   under EBC2. This situation may allow for *Potamocorbula* to recruit farther into the central Delta,
12   and, conversely, reduce available habitat for *Corbicula*, which requires more freshwater conditions
13   (<2 ppt). These invasive clams have the potential to reduce food production and export from the
14   Restoration Opportunity Areas (ROAs).

15   **Funding efforts that prevent the introduction of new invasive species (*CM20 Recreational Users***
16   ***Invasive Species Program*) would benefit covered fish species in the Plan Area.**

17   A key component of an integrated aquatic invasives program is prevention, which incorporates
18   regulatory authority, risk analysis, knowledge of introduction pathways, and inspections.
19   Specifically, efforts that prevent the transport of invasive species by requiring recreational boats to
20   be properly cleaned, drained, and dried after leaving a water body that could harbor invasive
21   mollusk species are considered beneficial.

22   While no feasible control measures are known for eradicating well-established invasive mollusks
23   such as *Corbicula* and *Potamocorbula*, prevention of further invasions is critical to avoid further
24   stress to the Delta ecosystem.

25   ## 5.F.0.2.4   *Microcystis*

26   **Changes to water operations (*CM1 Water Facilities and Operation*) and specific restoration actions**
27   **(*CM4 Tidal Natural Communities Restoration*) that reduce flows and increase water residence**
28   **times in the Delta may facilitate blooms of *Microcystis,* reducing the quantity and quality of the**
29   **food supply and increasing toxic exposure of covered fish species to microcystins.**

30   *Microcystis* blooms are facilitated by warmer temperatures, low freshwater flows, and high
31   residence time, among other factors. Water operations (CM1) would be dependent on the outcome
32   of the decision trees for spring and fall outflow. Implementation of the ESO scenario would generally
33   increase residence times throughout the Delta as a result of both tidal wetland restoration and
34   water operations, whether or not Fall X2 requirements are implemented.

35   In addition to residence times, warmer water temperatures are a major driver of *Microcystis* blooms.
36   Warmer water temperatures are expected to occur regionally as a result of climate change, and
37   could occur locally as a result of tidal wetland restoration. Thus, higher water temperatures may
38   have a greater effect on the potential for *Microcystis* blooms than changes associated with changed
39   water operations under CM1.

40   An accumulation of *Microcystis* could offset some of the foodweb benefits of restoration by reducing
41   zooplankton production, fish food quality, and fish feeding success and may also increase exposure
42   of covered fish to toxins (microcystins).

1   Appendix 5.F
2   # Biological Stressors and Covered Fish

3
4   # Contents

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Tables

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Figures

1 # Acronyms and Abbreviations

°C	degrees Celsius
AB	Assembly Bill
BAEDN	Bay Area Early Detection Network
BAFF	Bio-Acoustic Fish Fence
Bay-Delta	San Francisco Bay/Sacramento–San Joaquin River Delta
BDCP	Bay Delta Conservation Plan
BiOp	biological opinion
BMP	best management practice
CALFED	CALFED Bay-Delta Program
Cal-IPC	California Invasive Plant Council
CCF	Clifton Court Forebay
CDFA	California Department of Food and Agriculture
CDFW	California Department of Fish and Wildlife
Central Valley Water Board	Central Valley Regional Water Quality Control Board
CEQA	California Environmental Quality Act
cfs	cubic feet per second
cm	centimeter
CM	conservation measure
CSTARS	Center for Spatial Technologies and Remote Sensing
CVP	Central Valley Project
D-1641	State Water Resources Control Board water right Decision 1641
DBW	California Department of Boating and Waterways
Delta	Sacramento–San Joaquin River Delta
DO	dissolved oxygen
DPM	Delta Passage Model
DRERIP	Delta Regional Ecosystem Restoration Implementation Plan
EBC	existing biological conditions
EDCP	Egeria Densa Control Program
EIR	environmental impact report
ELT	early long-term
EPA	U.S. Environmental Protection Agency
ERP	Ecosystem Restoration Program
ESA	Endangered Species Act
ESO	evaluated starting operations
FAV	floating aquatic vegetation
fps	feet per second
GCID	Glenn Colusa Irrigation District
GRTS	Generalized Random Tessellation Stratified
IAV	invasive aquatic vegetation
km	kilometers
km^2	square kilometers

LLT	late-long term
LOC	Level of Concern
LSZ	low-salinity zone
m/s	meters per second
m^3	cubic meters
mg/L	milligrams per liter
mm	millimeters
MTL	mean tide level
NH_3	ammonia
NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric turbidity units
OMR	Old and Middle River
POC	particulate organic carbon
POD	pelagic organism decline
ppt	parts per thousand
RGR	relative growth rate
ROA	Restoration Opportunity Area
SAV	submerged aquatic vegetation
SWAMP	Surface Water Ambient Monitoring Program
SWP	State Water Project
USDA-ARS	U.S. Department of Agriculture, Agriculture Research Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VAMP	Vernalis Adaptive Management Plan
WHCP	Water Hyacinth Control Program
µM/L	micromoles per liter

1

This appendix focuses on the evaluation of Bay Delta Conservation Plan (BDCP) conservation measures that reduce key biological stressors and provide potential benefits to the Sacramento–San Joaquin River Delta (Delta) ecosystem at landscape, community, and species scales with a focus on covered fish species. Biological stressors examined include invasive aquatic vegetation (IAV), predation, invasive mollusks, and biotoxins. As described in Chapter 3, *Conservation Strategy*, the conservation measures address a wide spectrum of aquatic and terrestrial environmental stressors across the Plan Area. The combined effect of implementing all of the conservation measures on the Delta ecosystem at various scales is assessed in Chapter 5, *Effects Analysis*. The analysis in this appendix is a qualitative evaluation of potential outcomes (beneficial and detrimental) of implementing the conservation measures designed to reduce four key biological stressors on the covered fish. It is based on information obtained from the scientific literature; consultations with local experts; and conceptual models of key processes, habitats, and covered fish species in the Delta. The conceptual models that were reviewed included models developed previously by the CALFED Bay-Delta Program (CALFED) Ecosystem Restoration Program (ERP) implementing agencies (California Department of Fish and Wildlife [CDFW], U.S. Fish and Wildlife Service [USFWS], and National Marine Fisheries Service [NMFS]) as part of the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP). Those conceptual models were developed to aid in CALFED's planning of potential ecosystem restoration actions in the Delta and are relevant to the conservation strategy.

This appendix is organized into seven primary sections.

- Section 5.F.1, *Aquatic Biological Stressors and the BDCP Conservation Strategy*

- Section 5.F.2 *Conservation Measures*

- Section 5.F.3 *Methods for Analysis*

- Section 5.F.4, *Invasive Aquatic Vegetation*

- Section 5.F.5, *Fish Predation*

- Section 5.F.6, *Invasive Mollusks*

- Section 5.F.7, *Microcystis*

Each stressor section includes an overview of the stressor, a conceptual model, an overview of the relevant conservation measures, an analysis of the effects of implementing conservation measures, a discussion of uncertainties and research needs, and conclusions. References are at the end of this appendix.

5.F.1 Aquatic Biological Stressors and the BDCP Conservation Strategy

Biological stresses are associated with the diverse interactions that occur among organisms of the same or different species. Biological stresses can result from competition, herbivory, predation,

1   parasitism, toxins, and disease. A wide variety of human activities can cause or exacerbate biological
2   stress. The introduction of invasive species is the most prevalent cause of biological stress for
3   covered fish in the Delta. For the purposes of this discussion, invasive species generally are
4   considered those nonnative species that adversely affect the habitats and bioregions they invade.

5   The Delta is considered one of the most invaded estuaries in the world (Cohen and Carlton 1995).
6   Species introductions have been increasing since at least the nineteenth century as a function of
7   increasing trade, boat traffic, and recreation, as well as resource management activities. Numerous
8   taxa have been introduced, including copepods, shrimp, amphipods, bivalves, fish, and both rooted
9   and floating plants. Many pelagic species have been introduced through ballast water releases from
10 large ships directly into the estuary. As a result, many of these introduced species originate from
11 estuaries around the Pacific Rim, particularly copepods and mollusks. More than 250 nonnative
12 aquatic and plant species have been introduced into the Delta (Cohen and Carlton 1995). Of these, at
13 least 185 species have become established, and many have altered the Delta's ecosystem. Current
14 estimates suggest that more than 95% of the biomass in the Delta is composed of nonnative species.
15 These introductions have resulted in a host of mechanisms causing biological stress on covered fish
16 species.

17 Reducing the effects of biological stressors is an important component of the overall conservation
18 strategy in order to meet the goals and objectives for covered fish (Chapter 3, *Conservation*
19 *Strategy*). This appendix examines the effects of implementing the 10 conservation measures that
20 address the following four key biological stressors (Table 5.F.2-1).

21 **Table 5.F.2-1. Biological Stressors in the Delta and Associated BDCP Conservation Measures**

Delta Biological Stressor	Conservation Measures
Invasive Aquatic Vegetation Fish Predation Invasive Mollusks *Microcystis*	*CM1 Water Facilities and Operation* *CM2 Yolo Bypass Fisheries Enhancement* *CM4 Tidal Natural Communities Restoration* *CM5 Seasonally Inundated Floodplain Restoration* *CM6 Channel Margin Enhancement* *CM13 Invasive Aquatic Vegetation Control* *CM15 Localized Reduction of Predatory Fishes* *CM16 Nonphysical Fish Barriers* *CM20 Recreational Users Invasive Species Program* *CM21 Nonproject Diversions*

22

23   **5.F.1.1   Invasive Aquatic Vegetation**

24 In the Delta, IAV reduces the amount and suitability of habitat for covered fish species through
25 adverse effects on water quality and the foodweb and by physically obstructing covered fish species'
26 access to habitat. Dense stands of IAV displace native aquatic plants and provide suitable habitat for
27 nonnative fish species, which in turn displace native species through competition and predation. The
28 two most abundant IAV species in the Delta are Brazilian waterweed (*Egeria densa*), commonly
29 referred to as *Egeria*, and water hyacinth (*Eichhornia crassipes*).

30 *Egeria* has been present in the Delta for about 50 years and water hyacinth for more than 100 years.
31 *Egeria* is a rooted aquatic perennial plant that grows in shallow, freshwater areas of the Delta. The

1   plant forms very dense stands and is now the most abundant submerged aquatic vegetation (SAV) in
2   the Delta.

3   Water hyacinth is a floating perennial plant that inhabits calm backwater areas or areas with low
4   velocities and has become one of the dominant components of floating aquatic vegetation (FAV) in
5   these areas. Because the plant is not rooted in the substrate, its distribution is influenced by water
6   currents and prevailing wind. During the spring and summer, the dominant westerly winds often
7   hold the plants against the lee shorelines or in backwaters of the Delta. In off-channel and backwater
8   sites, water hyacinth mats can become dense enough to close off open water completely. In the fall,
9   when the seasonally predominant westerly winds decline, mats of hyacinth will float out into the
10   main channels where they are moved about by the river and tidal currents.

11   To address the adverse effects of these two IAV species on navigation, the California Department of
12   Boating and Waterways (DBW) was mandated under state legislation to control *Egeria* and water
13   hyacinth in the Delta and its tributaries. DBW began treating water hyacinth in 1983 and *Egeria* in
14   2001 and established an extensive program of field research, toxicity testing, and water quality and
15   efficacy monitoring. The programs have found that herbicide application is the most effective
16   treatment for *Egeria* in the Delta, and herbicide with some mechanical treatment is the best
17   available treatment for water hyacinth. Since herbicide applications began, DBW typically treated
18   several hundred acres each year, often more than 1,000 acres and up to 2,500 acres in some years.
19   Two conservation measures, *CM13 Invasive Aquatic Vegetation Control* and *CM20 Recreational Users*
20   *Invasive Species Program*, are likely to reduce the biological stress associated with IAV.

5.F.1.2   Fish Predation

22   Although predation is a natural part of aquatic community dynamics, increased predation rates have
23   been identified as a stressor for covered fish species, especially juvenile Chinook salmon (Good et al.
24   2005; Moyle 2002; National Marine Fisheries Service 2009), steelhead (Clark et al. 2009; National
25   Marine Fisheries Service 2009), and delta smelt (Baxter et al. 2008). Predator-prey dynamics are
26   influenced by many interacting factors that directly and indirectly influence prey encounter and
27   capture probabilities (Mather 1998; Nobriga and Feyrer 2007; Lindley and Mohr 2003). Elevated
28   predation rates are considered a potential indirect effect of water diversion operations (Brown et al.
29   1996) and a potential hindrance to shallow-water habitat restoration (Brown 2003; Nobriga and
30   Feyrer 2007).

31   Predatory fish species of particular concern in the Delta are striped bass (*Morone saxatilis*),
32   largemouth bass (*Micropterus salmoides*), and Sacramento pikeminnow (*Ptychocheilus grandis*).
33   Nobriga and Feyrer (2007) found numerous invertebrate and fish taxa in the diets of these common
34   species. Many predatory fish species, such as striped bass and largemouth bass, are nonnative,
35   although the Sacramento pikeminnow is a native species. Habitat structure and heterogeneity can
36   affect opportunities for encounter and capture of fish species of concern by predators. In open water
37   habitats, striped bass are the most likely primary predator of juvenile and adult delta smelt. Other
38   species, such as largemouth bass, are ambush predators that remain close to cover such as
39   submerged structures or aquatic vegetation.

40   A number of conservation measures are likely to reduce the biological stress associated with fish
41   predation. These include CM1 through CM6, CM13, CM16, and CM21. In particular, *CM15 Localized*
42   *Reduction of Predatory Fishes* will reduce local abundance of predatory fish and eliminate or modify
43   holding habitat for predators at selected locations of high predation risk ("predation hotspots").

5.F.1.3   Invasive Mollusks

Heavy grazing on phytoplankton by two species of invasive clams has contributed to changes in the foodweb supporting the Delta's fish species. Water salinity is a primary factor limiting clam abundance. The overbite clam (*Potamocorbula amurensis*) occurs in marine to brackish waters, and the Asian clam, *Corbicula fluminea,* is found in the freshwater Delta.

High rates of clam grazing reduce the abundance and species composition of the phytoplankton that supply food for the invertebrate prey of many of the Delta's fish species (Alpine and Cloern 1992; Jassby et al. 2002). *Potamocorbula* is capable of filtering the entire water column over Delta channels more than once per day and over shallows almost 13 times per day (Werner and Hollibaugh 1993). This filtration rate exceeds the phytoplankton's specific growth rate. As a result, summer phytoplankton blooms that had occurred annually in the northern bay in earlier years essentially disappeared after *Potamocorbula* became established, and spring blooms have become rare events.

Reductions in calanoid copepods that provide food for delta smelt (Bennett 2005) have been related to declines in phytoplankton and also to direct feeding by clams on copepod naupalii (Kimmerer et al. 1994; Kimmerer and Orsi 1996; Orsi and Mecum 1996; Mueller-Solger et al. 2002). A major decline in the native mysid shrimp, an important major prey item of longfin smelt juveniles and adults (Rosenfield and Baxter 2007), is attributed to competition with *Potamocorbula* for phytoplankton (Orsi and Mecum 1996).

The clams also have become a major portion of the diets of consumers that feed at or near the bottom, including several species of diving birds and bottom-feeding fishes (Nichols et al. 1990). While this has provided a new food resource, it has also had adverse effects on these species because the clams concentrate selenium, a toxic substance. This has led to bioaccumulation in white sturgeon, Dungeness crab, and Sacramento splittail at levels known to cause reproductive problems and developmental deformities in fish (Stewart et al. 2004). Background on selenium in the Delta and the potential for BDCP to affect selenium bioavailability is provided in Appendix 5.D, *Contaminants*.

The presence of invasive clams may reduce the benefits to fish species of the conservation measures related to habitat restoration, but a number of the conservation measures also may help reduce their adverse effects by affecting habitat suitability. Relevant conservation measures include *CM1 Water Facilities and Operation*, *CM4 Tidal Natural Communities Restoration*, and *CM6 Channel Margin Enhancement.* A preventative measure, *CM20 Recreational Users Invasive Species Program*, is intended to reduce the risk of future invasions by other mollusks such as zebra mussels and quagga mussels.

5.F.1.4   *Microcystis*

Microcystis aeruginosa (*Microcystis*) is a cyanobacterium that produces microcystin, a liver toxin that can have detrimental effects on the health of exposed aquatic organisms as well as humans (World Health Organization 1999). *Microcystis* can reach very high densities ("bloom") in the Delta, negatively affecting phytoplankton, zooplankton, and covered fish species (Lehman et al. 2008, 2010; Ger et al. 2010; Acuña et al. 2012). Blooms of *Microcystis* have been observed from June to November throughout the freshwater Delta since 1999 (Lehman et al. 2005, 2008), with peaks in abundance in September (Acuña et al. 2012). Lehman and coauthors (2010) found abundance

1   greatest in the western and central Delta, with the highest densities near Old River at Rancho Del
2   Rio and the San Joaquin River at Antioch.

3   *Microcystis* blooms have been associated with declines in delta smelt, striped bass, and threadfin
4   shad, along with their calanoid copepod prey (Sommer et al. 2007; Baxter et al. 2010). Feeding trials
5   have shown that the calanoid copepods, *Eurytemora affinis* and *Pseudodiaptomus forbesi*, experience
6   significant mortality when *Microcystis* is 10% or more of the diet (Ger et al. 2010). *Microcystis*
7   blooms are known to reduce copepod feeding and survival in the south Delta and the uppermost
8   portions of the west Delta (e.g., Franks Tract) (Lehman 1996; Lehman et al. 2005, 2008, 2010).
9   Laboratory feeding experiments found that *Microcystis* decreased growth and increased
10   malnutrition, severe liver lesions, and ovarian degeneration in threadfin shad (Teh et al. 2010).
11   Liver lesions are found in striped bass (*Morone saxatilis*) and Mississippi silversides (*Menidia*
12   *audens*) exposed to microcystin (Lehman et al. 2010).

13   The increase in *Microcystis* has occurred during a time of increases in water clarity, water
14   temperature, and water residence time in the Delta (Lehman et al. 2008). Increasing water clarity
15   during the last several decades (Kimmerer 2004; Nobriga et al. 2008) may be a long-term
16   contributing factor to *Microcystis* blooms. Warmer water temperatures along with low flows and
17   long residence time in summer, or poor flushing and long residence time during droughts, promote
18   the development and persistence of *Microcystis* blooms in the Delta (Lehman et al. 2008, 2010;
19   Meyer et al. 2009) and other estuaries (Pearl and Huisman 2008). *Microcystis* is more abundant in
20   the Delta in dry compared to wet years, and high abundances were observed during low flow
21   conditions in 2007 and 2008 (Baxter et al. 2010 citing unpublished observations by P. Lehman).
22   During low flow conditions in the summer of 2007, blooms of *Microcystis* spread downstream to the
23   western Delta.

24   *Microcystis* blooms peak in the central Delta when summer water temperatures reach 20 to
25   25 degrees Celsius (°C) (Lehman et al. 2008). An association between water temperature and
26   *Microcystis* blooms in the Delta is supported by the upward trend in spring-summer mean water
27   temperature in the freshwater Delta between 1996 and 2005 (Jassby 2008). It is hypothesized that a
28   smaller than average *Microcystis* bloom in 2010 may have been due to lower summer water
29   temperatures than in previous years (Mioni 2012).

30   # 5.F.2   Conservation Measures

31   The following sections briefly describe the conservation measures that could affect covered fish
32   species or the outcome of other conservation measures included in the evaluated starting
33   operations.

34   ## 5.F.2.1   CM1 Water Facilities and Operation

35   The proposed new North Delta Diversion will include three separate onshore intake structures on
36   the Sacramento River between Clarksburg and Courtland. The vulnerability of covered fish to
37   predation at the new north Delta intake structures is, to a large extent, dependent on the physical
38   characteristic of each structure, whether fish would be concentrated or disoriented, and areas of
39   turbulence and lower velocity refuge habitat that attract predatory fish. Relative to other intake
40   design alternatives, the proposed onshore diversions have minimal structures in the main flow of
41   the river. This reduces areas where predators can aggregate.

1   In addition, operations of the south Delta State Water Project (SWP) and Central Valley Project
2   (CVP) facilities will change. Predation in the Clifton Court Forebay (CCF) has been documented to be
3   high for covered fish species. Striped bass readily enter and exit the forebay through the radial gates.
4   As pumping at the south Delta is reduced in coordination with the exports at the north Delta facility,
5   entrainment into the CCF will be reduced, and consequently predation losses are expected to be
6   reduced.

5.F.2.2   CM2 Yolo Bypass Fisheries Enhancement

8   *CM2 Yolo Bypass Fisheries Enhancement* intends to improve passage at the Fremont Weir and
9   increase Yolo Bypass inundation, which may reduce predation risk on migrating covered fish by
10   providing a migration route with potentially lower predation and entrainment risk (i.e., avoiding the
11   north and south Delta diversions). Enhancement measures also include increasing flows into the
12   Yolo Bypass and creating additional floodplain habitat in the area. The creation of more floodplains
13   is intended to increase habitat availability for covered species. Predatory fish species also have been
14   observed in restored seasonal floodplain habitats in the Yolo Bypass (Feyrer et al. 2006) and
15   Cosumnes River (Moyle et al. 2007), mainly in ponded areas. However, native covered species
16   appear to benefit proportionally more from floodplains than do many nonnative species (Moyle et
17   al. 2007). Juvenile Chinook salmon and splittail are adapted to this seasonal inundation pattern,
18   which provides valuable rearing habitat in late winter and spring. Largemouth bass prefer
19   permanent ponds, and their spawning and rearing occur after most floodplains have drained in late
20   spring and early summer. Striped bass are pelagic and rarely found on shallow floodplains. The
21   effect of the Yolo Bypass restoration on predation rates of covered fish is uncertain.

5.F.2.3   Aquatic Habitat Restoration (CM4, CM5, CM6, CM7)

23   Aquatic habitat restoration will increase the amount of tidal wetlands (*CM4 Tidal Natural
24   Communities Restoration*), seasonally inundated floodplains (*CM5 Seasonally Inundated Floodplain
25   Restoration*), channel margin habitat (*CM6 Channel Margin Enhancement*), and riparian vegetation
26   (*CM7 Riparian Natural Community Restoration*) in the Delta. This is expected to provide cover,
27   foraging, spawning, and rearing habitat for many covered species as well as for certain predators.
28   The benefits and risks will vary depending on species and life stage, which affect habitat use.

5.F.2.4   CM13 Invasive Aquatic Vegetation Control

30   CM13 is intended to prevent the introduction and control the spread of IAV, including both SAV and
31   FAV, that degrades habitat for covered fish species. IAV control will be conducted as required with
32   the focus on areas that provide the greatest biological benefits to covered fish species: in subtidal
33   habitats restored under CM4, IAV source populations adjacent to or hydrologically connected to
34   restoration sites, salmonid migration routes, and other areas deemed biologically important to
35   covered fish species. Some tidal habitat restoration sites may require IAV treatment prior to
36   restoration. Other priority areas could include established *Egeria* source populations that are near
37   or upstream of restoration areas that could spread into the restored sites.

38   Implementation of CM13 will follow approved protocols and use permitted herbicides based on the
39   long-term experience of the DBW in implementing their control programs (*Egeria densa* Control
40   Program [EDCP] and Water Hyacinth Control Program [WHCP]) and monitoring the effects
41   (California Department of Boating and Waterways 2006, 2009) to comply with permit conditions. In

1   addition to DBW's ongoing programs, CM13 proposes to treat approximately 1,700 to 3,400 acres
2   per year. Note that CM13 is not designed or intended to completely eradicate IAV from the Delta but
3   rather to control and minimize IAV extent in and near restored habitat through treatment at
4   targeted areas. The Implementation Office will work with DBW to prioritize control of source
5   populations of *Egeria* and water hyacinth (currently the IAV species of highest concern) that are
6   hydrologically connected to restoration sites in a way that could facilitate the spread of propagules
7   from the source population to the restoration sites.

8   Control methods currently employed by DBW are primarily application of herbicides, with limited
9   mechanical removal of small infestations of water hyacinth by "herding," in which small rafts of
10   water hyacinth are pushed into a flowing channel to be washed downstream into saline water where
11   they die. The conservation strategy methods of control will be dictated by site-specific conditions.
12   Application of herbicides or other means to control IAV will be timed to eliminate or minimize
13   potential negative effects on covered species. Chapter 3, *Conservation Strategy*, discusses this
14   conservation measure in detail.

15   CM13 also includes other important components of an effective invasive plant control program
16   (Myers et al. 2000): support of early detection and rapid response programs; research on effective
17   treatment methods, which would include research on the biology of potential and known IAV
18   species; and investigation of biological control methods. The Implementation Office will partner
19   with existing programs operating in the Delta to perform risk assessment and subsequent
20   prioritization of treatment areas to strategically and effectively reduce expansion of the multiple
21   species of IAV in the Delta. This risk assessment will dictate where initial control efforts will occur to
22   maximize the effectiveness of CM13.

23   *CM20 Recreational Users Invasive Species Program* is an additional important component that
24   includes watercraft inspections and public education on the transport and introduction of IAV and
25   the consequences of introduction.

5.F.2.5   CM15 Localized Reduction of Predatory Fishes

27   The purpose of CM15 is to improve survival of covered fish species by locally reducing numbers of
28   predatory fish and/or modifying potential holding habitat at selected sites of high predation loss
29   (predation "hotspots"). This experimental pilot program will focus on reduce mortality of migrating
30   juvenile salmonids. The pilot studies will test the effectiveness of various techniques to physically
31   remove predatory fish at selected sites. Monitoring and research will guide adaptive management to
32   refine and potentially expand predator reduction actions at a broader scale if effective. This process
33   will be directed by the Adaptive Management Team, in coordination with the Implementation Office
34   (Chapter 7, *Implementation Structure*). Further details are provided in Chapter 3, Section 3.4.15.

35   The most plausible and feasible initial actions would be localized reduction of selected predatory
36   fish species in predation "hotspots" and modification of habitat features that tend to increase
37   predation risk. Likely predator "hotspots" in the Delta are indicated in Figure 5.F.3-1, including:

38   ●   **Clifton Court Forebay.** Native fish entrained in CCF experience high prescreen losses (75 to
39   90%), presumably due to predation (Gingras 1997; Clark et al. 2009; Castillo et al. in press).
40   Striped bass are known to readily enter and leave through the radial gates (Gingras 1997).

41   ●   **Central Valley Project Intakes.** Salmon experience approximately 15% prescreen loss at the
42   south Delta CVP intakes, attributed to predation (Gingras 1997; Clark et al. 2009).

1   ● **Head of Old River.** Nonphysical barriers have been tested here to prevent fish from entering
2   Old River and continuing to the south Delta pumping plants. However, acoustic-tagging studies
3   of juvenile hatchery salmon documented very high predation losses to striped bass patrolling
4   the area and swimming along the barrier infrastructure (Bowen et al. 2009).

5   ● **Georgiana Slough.** Acoustic-tag studies indicate that survival rates of juvenile salmon released
6   near Walnut Grove are much greater for juveniles traveling down the Sacramento River
7   mainstem instead of down Georgiana Slough (Vogel 2008; Perry et al. 2010). It is assumed that
8   the lower survival of juvenile salmon in Georgiana Slough is a result of greater predation.

9   ● **Old and Middle Rivers.** In general, survival rates are lower for juvenile salmon migrating
10 through the central Delta.

11 ● **Franks Tract.** This flooded island has the highest levels of invasive Brazilian waterweed in the
12 Delta (Underwood et al. 2006), which has facilitated intensive colonization by largemouth bass.
13 Striped bass are also common in Franks Tract.

14 ● **Paintersville Bridge.** Multiple timber pilings meant to protect the bridge pilings and guide
15 navigation can alter flow fields, while the structures provide predator holding habitat.

16 ● **Geomorphic Channel Features.** The scour hole at the head of Old River can allow predators
17 such as striped bass and catfish to congregate and ambush prey.

18 ● **Human-Made Submerged Structures.** Structures such as abandoned boats, bank revetments,
19 and piers can attract predators as hiding areas and alter local hydraulic patterns that disorient
20 small fish.

21 ● **Salvage Release Sites.** The fish salvaged from CVP/SWP south Delta export facilities are
22 released daily via pipes located at only a few Delta locations. Over time, this has provided a
23 limited number of obvious places that predators can aggregate and wait for dead, dying, and
24 disoriented prey fishes. Refinements of release operations may provide some additional benefits
25 to reduce predation.

26 In addition to these existing predation hotspots, the BDCP may create new hotspots.

27 ● **North Delta water diversion facilities.** The three intakes included in *CM1 Water Facilities and*
28 *Operation* may create predator hotspots. Large intake structures have been associated with
29 increased predation by creating predator ambush opportunities and flow fields that disorient
30 juvenile fish (Vogel 2008).

31 ● **Nonphysical barriers.** The construction and use of nonphysical barriers under *CM16*
32 *Nonphysical Fish Barriers* may create predator hotspots.
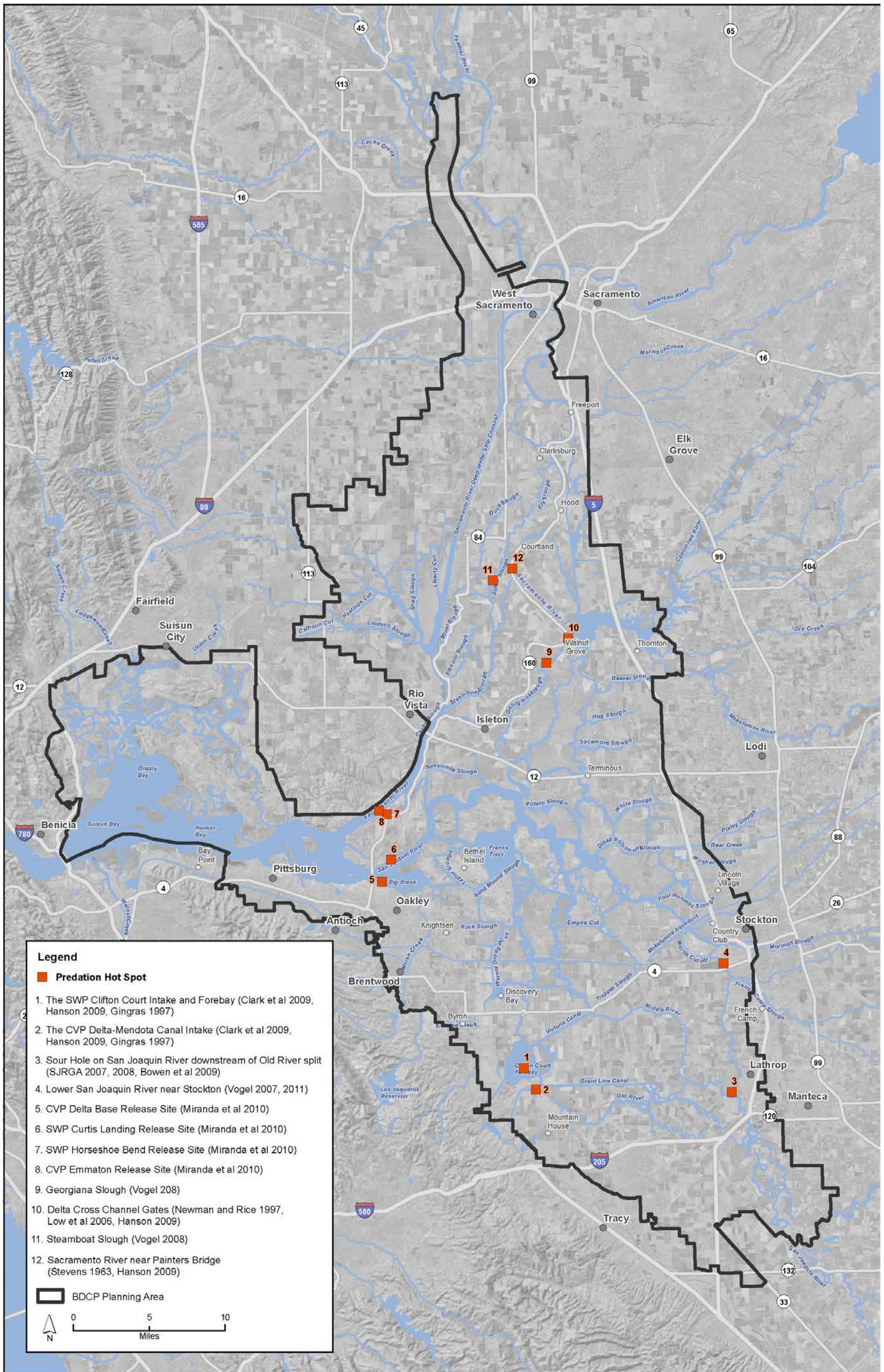
Legend

■ Predation Hot Spot

1. The SWP Clifton Court Intake and Forebay (Clark et al 2009, Hanson 2009, Gingras 1997)

2. The CVP Delta-Mendota Canal Intake (Clark et al 2009, Hanson 2009, Gingras 1997)

3. Sour Hole on San Joaquin River downstream of Old River split (SJRGA 2007, 2008, Bowen et al 2009)

4. Lower San Joaquin River near Stockton (Vogel 2007, 2011)

5. CVP Delta Base Release Site (Miranda et al 2010)

6. SWP Curtis Landing Release Site (Miranda et al 2010)

7. SWP Horseshoe Bend Release Site (Miranda et al 2010)

8. CVP Emmaton Release Site (Miranda et al 2010)

9. Georgiana Slough (Vogel 208)

10. Delta Cross Channel Gates (Newman and Rice 1997, Low et al 2006, Hanson 2009)

11. Steamboat Slough (Vogel 2008)

12. Sacramento River near Painters Bridge (Stevens 1963, Hanson 2009)

☐ BDCP Planning Area

Figure 5.F.3-1. Representative Locations of Known or Suspected High-Level Predation (Hotspots) in the Delta

1   ### 5.F.2.5.1   Reduce Predatory Fish at Hotspots

2   Pilot projects to reduce predatory fish at hotspots will incorporate a study design similar to that
3   used by Cavallo and coauthors (2012). This approach would be implemented in river reaches with
4   known high predation loss, and if necessary at the North Delta Diversion intake structures. The
5   study design would compare treated and untreated (control) reaches, or above and below treated
6   areas (e.g., scour hole at the head of Old River). Experimental reaches would be relatively short (1 to
7   2 kilometers [km] or less) to ensure higher reduction efficiency. Only physical removal techniques
8   will be tested, such as boat electrofishing, hook-and-line fishing, and capture by net or trap (e.g., gill
9   netting, hoop net, fyke trap, seining). Multiple treatments would be applied to the treated river reach
10   to help develop an estimate of effectiveness. Sustained removal efforts would likely be necessary to
11   maintain local reductions in predators. Bycatch of covered fish species would be documented in
12   order to refine capture methods.

13   Another approach to test would be a predator lottery fishing tournament at hotspots such as CCF or
14   along mainstem San Joaquin River (Cavallo pers. comm.). Predatory fish would be tagged and
15   released into these predator hotspots, with specially coded tags that are redeemable for prizes and
16   awards. These tournaments would be designed to encourage intensive angling pressure at a
17   particular location and period of time, targeting specific predatory fish species (i.e., striped bass,
18   largemouth bass). The time and location for release would be widely advertised.

19   ### 5.F.2.5.2   Reduce Suitable Habitat for Predators at Hotspots

20   Modifying or eliminating habitat features can reduce holding habitat for predatory fish. Examples
21   include submerged human-made structures (e.g., abandoned boats, derelict structures, bridge
22   piers), water diversion facilities (e.g., intakes, forebays) (Vogel 2008), channel features (e.g., scour
23   hole at head of Old River) (Bowen et al. 2009), stands of invasive aquatic vegetation (Nobriga et al.
24   2005) (to be treated under *CM13 Invasive Aquatic Vegetation Control*), and nonproject diversions
25   (see also *CM21 Nonproject Diversions*).

26   To reduce predation loss of salvaged covered fishes, another approach would modify salvage release
27   methods, remove debris, and vary or increase release locations to avoid unintentionally creating
28   predator feeding stations at the release pipe (California Department of Water Resources 2010a).
29   This pilot experiment will increase the number of release sites from four to eight and remove debris
30   near salvage release sites monthly from October through June.

31   ## 5.F.2.6   CM16 Nonphysical Fish Barriers

32   Nonphysical barriers are intended to guide juvenile fish away from migration routes with low
33   survival and high predation risk toward safer routes. Early research focused on the use of an
34   acoustic (sound) barrier to deter salmon from entering Georgiana Slough (Hanson and San Luis &
35   Delta-Mendota Water Authority 1996). More recently, a nonphysical barrier called the Bio-Acoustic
36   Fish Fence (BAFF) has been deployed at the head of Old River (Bowen et al. 2009). Nonphysical
37   barriers currently used in the Delta include large in-water structures using BAFF technology, which
38   incorporates multiple stimuli such as directional strobe lighting, sound signals, and air bubble
39   curtains to contain the noise and form a wall of sound (Bowen et al. 2009; Bowen and Bark 2010;
40   ICF International 2010). These stimuli are intended to deter juvenile fish from passing and to choose
41   an alternative migration path. Preliminary results of the most recent studies, conducted in spring
42   2011, show these types of nonphysical barriers are effective in deterring juvenile salmon (McQuirk

1   et al. 2012). The submerged structures associated with the barrier infrastructure, however, have the
2   potential to attract predatory fish.

5.F.2.7   CM20 Recreational Users Invasive Species Program

4   Under CM20, the Implementation Office will fund a Delta Recreational Users Invasive Species
5   Program designed to implement actions to prevent the introduction of new invasive species into the
6   Plan Area. Funding will be provided to implement the CDFW Watercraft Inspection Program and
7   reduce the spread of existing aquatic invasive species via recreational watercraft, trailers, and other
8   mobile recreational equipment used in aquatic environments in the Delta. It will do this primarily by
9   educating recreational users about the importance of avoiding further introductions of aquatic
10   invasive species and by instituting recreational watercraft inspections that directly reduce the risk
11   of invasive species introduction and proliferation.

5.F.2.8   CM21 Nonproject Diversions

13   Nonproject diversions take natural surface waters in the Plan Area for purposes other than meeting
14   SWP/CVP water supply needs, mainly in-Delta agriculture and waterfowl rearing areas. An
15   estimated 2,200 nonproject diversions are used to irrigate crops in the Delta (Herren and Kawasaki
16   2001). These shore-based diversions operate using pumps or gravity flow, and almost all are small
17   (30 to 60-centimeter [cm] pipe diameter) and unscreened (Nobriga et al. 2004).

18   Under this conservation measure, the Implementation Office will help fund screening and/or
19   consolidation of these diversions to reduce entrainment of covered species, and may have the
20   indirect effect of reducing predation at these sites. The most common screen designs used in the
21   Sacramento Valley and Delta for diversions up to 500 cubic feet per second (cfs) are cylindrical or
22   cone screen systems that can be attached to the end of an intake pipe.

23   The intake structures of these nonproject diversions are potential sites for increased predation on
24   covered fish species. Consolidating diversions and reducing the amount of in-water structures could
25   reduce cover for nonnative predatory fish and potentially predation.

5.F.3   Methods for Analysis

5.F.3.1   Invasive Aquatic Vegetation Analysis

28   The analysis in this section is a qualitative evaluation of potential outcomes (beneficial and
29   detrimental) of implementing the conservation measures associated with reducing the effects of IAV
30   on covered fish species. It is based on information obtained from the scientific literature;
31   consultations with local experts; and conceptual models of key processes, habitats, and covered fish
32   species in the Delta. Review of conceptual models included models developed previously by the
33   CALFED ERP implementing agencies (CDFW, USFWS, and NMFS) as part of the DRERIP. A conceptual
34   model that includes the primary drivers, stressors, and their effects related to IAV spread and
35   growth was used as a guide for generating hypotheses, predicting outcomes, highlighting
36   uncertainties, and directing research.

37   The analysis also addresses the potential for success in controlling the IAV in the Delta, and
38   particularly in preventing it from colonizing Restoration Opportunity Areas (ROAs). Information

1   comes from research—both laboratory and field-based—on the ecology and physiology of the major
2   IAV species. Recent and ongoing research in the Delta has addressed growth rates of the major IAV
3   species and their mechanisms of invasion, and environmental factors that affect their growth and
4   spread, such as salinity and water flow. The most widespread and damaging IAV species in the Delta
5   currently is *Egeria*, and its potential to invade ROAs was analyzed by modeling the environmental
6   parameters in ROAs in relation to the ecological tolerances and responses of *Egeria*.

7   The DBW operates two well-established programs in the Delta to control water hyacinth and *Egeria*,
8   In addition to treating the target IAV species, the programs include intensive efficacy monitoring
9   and water quality monitoring. The programs also conducted research on toxicity effects on covered
10   species on the Delta. These control programs and their associated research and monitoring
11   programs provide important information on the relationship between the scale of treatment (acres
12   treated per year) and its efficacy in reducing the extent of the target IAV species, and on the
13   potential ecological effects of treatment on the scale conducted.

5.F.3.1.1   Invasive Aquatic Vegetation Effects on Covered Fish

15   The assumption behind *CM13 Invasive Aquatic Vegetation Control* is that IAV removal will benefit
16   covered fish species by (1) increasing turbidity, thereby increasing feeding in delta smelt and
17   reducing predation by visual predators; and (2) decreasing predation by removing a habitat that
18   supports predatory fish. Turbidity is an important flow-related habitat feature that correlates with
19   the presence of covered species such as delta smelt, and is discussed in detail in Appendix 5.C, *Flow,*
20   *Passage, Salinity, and Turbidity*. Information on the potential effects of IAV removal on turbidity
21   comes from several sources: small-scale field experiments on the effects of IAV on turbidity (from
22   the point of view of using IAV to improve water quality by reducing turbidity) (Reddy et al. 1983);
23   research on long-term Delta-wide trends in sediment supply (Wright and Schoellhamer 2004) and
24   IAV spread and the relationship between the two;(Hestir et al. 2010b); and limited observations in
25   the Delta on turbidity changes following a large-scale treatment to remove *Egeria* in Franks Tract
26   (Hestir et al. 2010a).

27   Information on the relationship between delta smelt and turbidity comes from the delta smelt
28   conceptual model (Nobriga and Herbold 2009), laboratory experiments on delta smelt feeding rates
29   in relation to different levels of turbidity, research on the effect of turbidity changes in triggering
30   spawning migration, and field surveys in the delta on habitat use and movements in delta smelt.

31   Information on the role of IAV in increasing predation on covered fish species comes primarily from
32   field observations in the Delta on the species of fish that inhabit dense IAV, especially *Egeria*.

5.F.3.1.2   Effectiveness of Invasive Aquatic Vegetation Control
Programs

35   The two IAV species of concern in the Delta, water hyacinth and *Egeria*, have been the subject of
36   DBW's major control programs beginning in 1983 for water hyacinth and 2001 for *Egeria*. The
37   results of these two long-term programs over the years, and their development of treatment
38   protocols and associated research programs on toxicity, water quality monitoring, and treatment
39   efficacy, provide important information on the scale of treatment, efficacy, and ecological effects. In
40   addition, the environmental documents and permits required for both programs under the federal
41   Endangered Species Act (ESA) and water quality regulation provide disclosure and analysis of the
42   environmental effects of the programs.

1   The key question addressed while reviewing the DBW programs is the potential for IAV treatment
2   on the scale proposed under CM13 to be effective in reducing the extent of IAV Delta-wide and in
3   limiting or preventing its colonization of the ROAs, while at the same time minimizing or avoiding
4   adverse effects on covered species and other aquatic organisms and water quality.

5   ### 5.F.3.1.3   Invasive Aquatic Vegetation Invasion Potential of ROAs

6   Restoration of aquatic habitats proposed under *CM4 Tidal Natural Communities Restoration* will
7   create additional suitable freshwater habitat for *Egeria* in the ROAs. Analysis of environmental
8   variables that control the distribution and growth of *Egeria* was undertaken to determine the
9   amount of area that would provide suitable conditions for *Egeria* within the ROA footprint areas.
10   The variables analyzed were water depth, salinity, water velocity, and turbidity. Based on the
11   conceptual model, suitable *Egeria* habitat was defined as aquatic areas less than 3 meters deep, with
12   salinity below 8 to 10 parts per thousand (ppt), and maximum annual water velocity less than 1.61
13   feet per second (fps).

14   # 5.F.3.2   Fish Predation Analysis

15   Best professional judgment based on the available scientific information was used to characterize
16   predator distribution and abundance within Delta habitats, covered fish species losses attributed to
17   predation, and the anticipated effectiveness of the predator reduction conservation measures on
18   predation effects in the Delta. Information came from studies of marked or radio-tagged steelhead,
19   Chinook salmon, and delta smelt at the SWP's CCF (Gingras 1997; Clark et al. 2009; Castillo et al. in
20   press) and Chinook salmon at the San Joaquin River and head of Old River (Bowen and Bark 2010).
21   Other studies provided information on Delta habitat use by covered fish species and nonnative
22   predators (Nobriga and Feyrer 2007) and the effectiveness of fish predator reduction efforts in the
23   Delta (Cavallo et al. 2012) and elsewhere (Mueller 2005; Porter 2010).

24   For the north Delta diversion facilities (*CM1 Water Facilities and Operation*), two approaches were
25   used to estimate predation-related effects. Bioenergetics modeling estimated relative consumption
26   by striped bass of juvenile Chinook salmon and splittail (Loboschefsky et al. 2012; Loboschefsky et
27   al. unpublished). In addition, a fixed estimate of 5% predation loss at each screened intakes was
28   used, based on predation assumptions from the Glenn Colusa Irrigation District (GCID) facility on
29   the upper Sacramento River (Vogel 2008).

30   For predation-related effects at the south Delta facilities, salvage-density and the Kimmerer (2008)
31   Old and Middle River (OMR) entrainment values were used to estimate pre-screen entrainment losses
32   that typically are ascribed to predation (Gingras 1997; Clark et al. 2009, Castillo et al. in press).

33   These methods are described in detail in the following sections.

34   ### 5.F.3.2.1   Bioenergetics Model for the North Delta Diversion

35   #### 5.F.3.2.1.1   Theory and Assumptions

36   Bioenergetics models provide a quantitative approach for estimating the energy budget of an
37   individual species by partitioning consumed energy to three components: metabolism, wastes, and
38   growth (Chipps and Wahl 2008). Because these models are driven by a mass-balance equation, they
39   are used mostly to estimate growth or consumption given information on other variables (Chipps
40   and Wahl 2008). The growth or consumption estimates of an individual species often are expanded

1   to the stock or population level. This is done by multiplying single fish dynamics by estimates of the
2   population size and cohort mortality (Hartman and Margaf 1992; Hansen et al. 1993), thereby
3   illustrating the energy allocation of the population.

4   The most common application of bioenergetics modeling is to estimate the dynamics of predator-
5   prey interactions. Often, estimates of population-level parameters such as food consumption or
6   growth of fish stocks are taken from these models and are linked in larger models to examine more
7   complex foodweb interactions such as predation rates, energy or nutrient cycling, and trophic
8   efficiency (Stewart et al. 1981; Hansen et al. 1993). Using these approaches, the rate at which
9   predators will consume prey populations, especially for sensitive fish populations, can be
10   quantitatively estimated over a given period of time. Moreover, such models can be a useful tool for
11   species conservation measures when used to compare estimated consumption of prey by predators
12   based on their responses to management actions and predator-prey interactions (see Hansen et al.
13   1993; Rand et al. 1995; Loboschefsky et al. 2012).

14   This bioenergetics model was developed by Loboschefsky and coauthors (2012) for striped bass in
15   the San Francisco estuary and modified by Loboschefsky and Nobriga (2010) for use in the
16   conservation strategy analysis. The model estimated striped bass annual consumption of migrating
17   juvenile salmon and Sacramento splittail at the north Delta intakes. Consumption estimates were
18   based on water temperature, striped bass size, and the density and size of prey encountered.

19   Application of the bioenergetics model involves the following assumptions:

20   ●   Bioenergetics models represent the best available scientific method to factor fish physiology
21   into estimates of prey consumption. The bioenergetics model–based consumption estimates are
22   subject to the input parameter sensitivities and assumptions described by Hartman and Brandt
23   (1993, 1995).

24   ●   Consumption estimates are highly sensitive to striped bass size because consumption increases
25   as a log-function of striped bass length. Thus, it was necessary to estimate adult striped bass
26   lengths by extrapolating beyond the length-weight ranges. This includes the potential for
27   overestimating or underestimating consumption depending on whether the length-weight
28   equation overestimates or underestimates the length of adult striped bass based on their
29   weight.

30   ●   The functional response equations are prey-dependent and density-dependent functions
31   developed for capture rates of common, nonnative prey fishes by striped bass. It is not known
32   how accurately these functions predict predator-prey dynamics involving rare native fish
33   species. However, this modeling step is necessary to estimate striped bass consumption in
34   response to changes in prey fish density. The covered fish species are narrow-bodied fish
35   lacking substantial fin spines. The same is true of the prey fishes for which the functional
36   response curves were developed. Thus, if used as recommended, the functional responses
37   should approximate striped bass predation of fishes other than those for which they were
38   developed.

39   ●   Predation of juvenile salmon is proportional to their relative abundance, regardless of size. This
40   bioenergetics model does not incorporate hunting or feeding efficiency into its parameters,
41   resulting in an overestimation of predation loss.

42   ●   Uncertainties exist for striped bass densities associated with structures. Estimates of predator
43   abundances are based on a few underwater pictures of predators observed holding around the

1   GCID fish screens (Vogel 2008) and extrapolated to estimate predator abundances at north Delta
2   intakes. These predators may be Sacramento pikeminnow, not striped bass, based on Vogel's
3   (1995) review of GCID studies.

4   ● Loboschefsky and Nobriga (2010) provide estimates of striped bass predation rates on "small
5   prey" and "large prey." This bioenergetics analysis incorporates only the large prey equation,
6   although smaller salmon fry would fall under the small prey category. The large prey predation
7   regression was based on data for small striped bass (69 to 478 millimeters [mm]); thus they
8   mainly reflect responses of juvenile striped bass. Therefore, they are not as applicable for larger
9   striped bass and for larger sized prey fishes.

10   ● Not all juvenile fish traveling past the proposed north Delta intakes may be vulnerable to the
11   increased predation risks associated with the structures. Human-made structures can create
12   water turbulence, which disorients juveniles fish and makes them more vulnerable to predators.
13   Some juveniles will not be affected by the increased turbulence or swim close to the intake
14   structures, but the model assumes an equal elevated predation risk across the Sacramento River
15   channel for all migrating juveniles. Therefore, predation risk may be overestimated. Similarly, a
16   small proportional of Sacramento River juvenile salmon population would outmigrate via the
17   Yolo Bypass, bypassing the north Delta intakes entirely.

18   Several of these assumptions in the bioenergetics model would lead to an overestimation of the
19   likely level of predation loss at the north Delta intakes.

5.F.3.2.1.2   Methods

21   The north Delta diversion bioenergetics model used the empirical data from Loboschefsky and
22   Nobriga (2012) for striped bass in the Delta, which were obtained from CDFW's mark-recapture
23   study (1969–2004). Additional data inputs used in the model were obtained from USFWS's Delta
24   Juvenile Fish Monitoring Program for juvenile Chinook salmon weekly catch and fork lengths (1994–
25   2006), and BDCP water quality model simulation for water temperatures.

26   To estimate the number of juvenile Chinook salmon consumed by striped bass at the north Delta
27   intakes, the following inputs were used in the model (Figure 5.F.4-1).

28   ● Weekly prey density for juvenile Chinook salmon (all races combined) (U.S. Fish and Wildlife
29   Service 1994–2006 trawl data).

30   ● Weekly striped bass fork length by age class (Loboschefsky and Nobriga 2010).

31   ● Weekly average water temperature (DSM2-QUAL).

32   ● Weekly Chinook salmon proportional abundance by race (U.S. Fish and Wildlife Service 1994–
33   2006 trawl data).

34   ● Weekly Chinook salmon average fork lengths by race (U.S. Fish and Wildlife Service 1994–2006
35   trawl data).

36   ● Estimated number of striped bass at north Delta intakes (Vogel 2008).

37   ● Striped bass age class composition (Loboschefsky and Nobriga 2010).

38   ● Chinook salmon average annual juvenile (and smolt-only) production for each race (California
39   Department of Fish and Game GrandTab 2010b; California Department of Water Resources

1   2001a; Cavallo et al. 2009; Fisher 1994; Killam 2009; Lee and Chilton 2007; Poytress and Carillo
2   2010; U.S. Fish and Wildlife Service unpublished data).

3   Estimates of splittail predation were based on the steps similar to those for juvenile Chinook
4   salmon, but inputs were based on monthly averages instead of weekly averages.
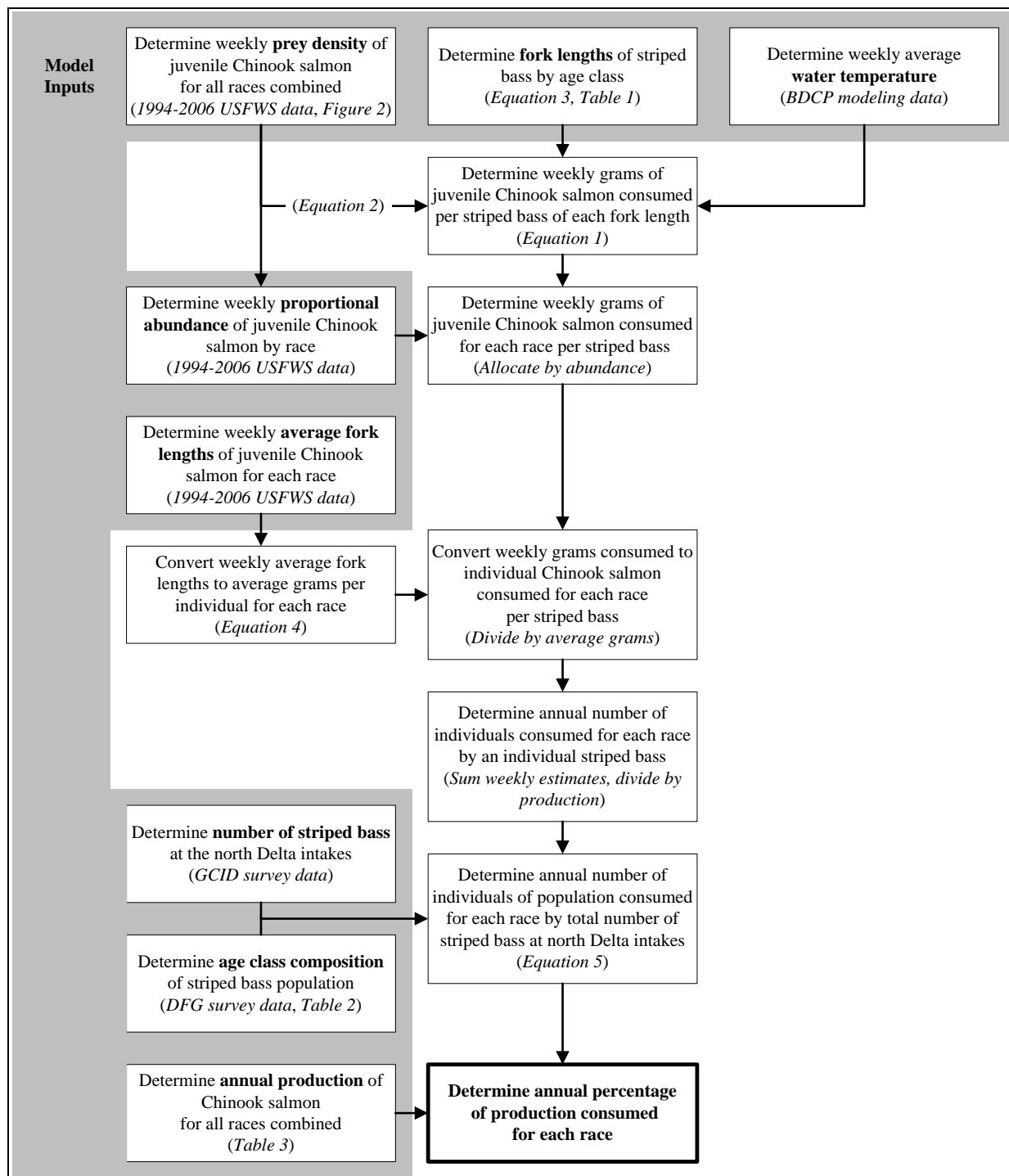
5
6   **Figure 5.F.4-1. BDCP Bioenergetics Model Calculation Steps**

1 The weekly consumption of juvenile salmon by an individual striped bass was modeled as a logistic
2 function of striped bass fork length in mm (*FL*), average water temperature in °C (*T*), and the
3 proportion of the diet composed of a particular prey taxon (*P*):

4      $C_{individual,\ weekly} = [0.002103(FL) + 0.02488(T) + 0.79336] * P$;   (Equation 1)

5   where *C* is the log transformed grams of prey consumed.

6 The equation used to predict *P* was expressed as:

7      $$P = \left(\frac{1}{1 + e^{(-5.8136 + 0.0091239\,FL + 0.72985\,CPUE)}} \right);$$ (Equation 2)

8   where *CPUE* = salmon density as $\log_{10}$-transformed number of salmon per 10,000 m^3 of water
9   sampled.

10 The salmon density estimates (weekly number of fish per 10,000 cubic meters [m^3]) combined for
11 all juvenile Chinook salmon races were collected from 1994–2006 trawling data in the Sacramento
12 River obtained from the USFWS's Delta Juvenile Fish Monitoring Program (Figure 5.F.4-2).

13 The logistic regressions that are used to estimate total consumption to consumption of a particular
14 prey are approximations of striped bass functional responses to changing prey density that were
15 developed from field data collected in the Delta (Nobriga and Feyrer 2008). The covered fish species
16 are relatively rare, and thus there were not enough found in stomachs (and in some cases not any)
17 to develop response equations specific to them. However, there is a large amount of scientific
18 literature on the feeding ecology of piscivorous fishes, and these modeled responses follow
19 expectation. The prey equation used above is the modeled response of striped bass to threadfin
20 shad.
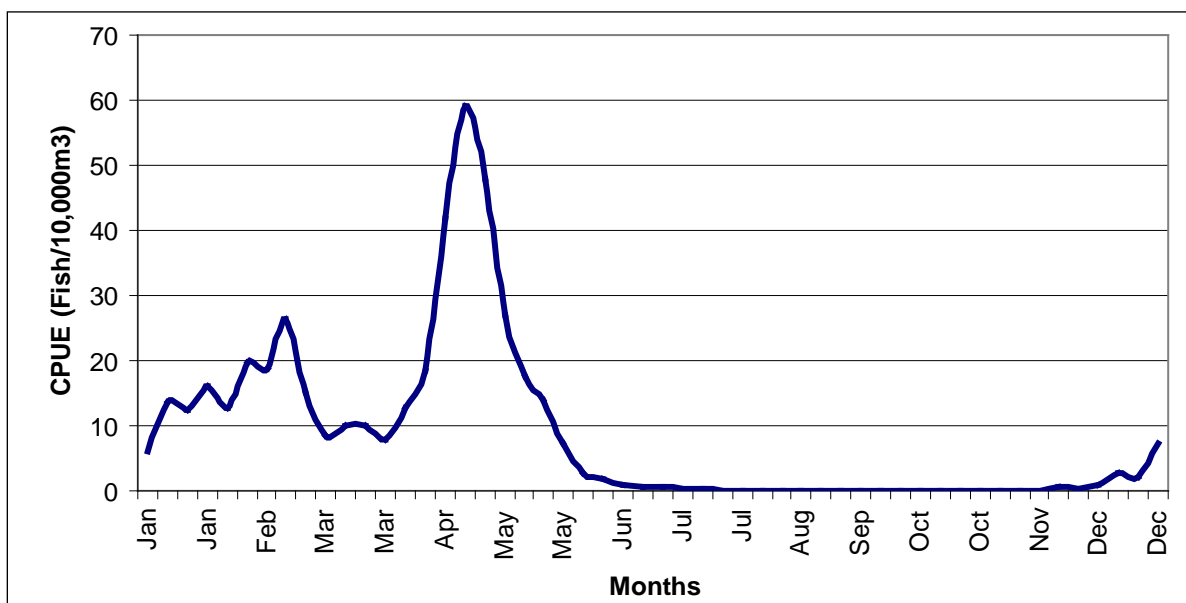
21

22 **Figure 5.F.4-2. Juvenile Chinook Salmon CPUEs (Fish/10,000 m^3) Collected from 1994–2006 Trawling in**
23 **the Sacramento River by the U.S. Fish and Wildlife Service**

1   The fork lengths of individual striped bass for each age class that were applied in the model were
2   taken from Loboschefsky and Nobriga (2010) (data shown in Table 5.F.4-1). These were calculated
3   based on the size of striped bass in weight (g), and converted to fork lengths (mm) using the length-
4   weight conversion of Kimmerer and coauthors (2005):

5   $$W = 0.0066 \cdot \left(\frac{1}{1 + e^{(-5.8136 + 0.0091239\,FL + 0.72985\,CPUE)}} \right) \cdot L^{3.12} ;$$ (Equation 3)

6   where W=striped bass weight in g, and L=striped bass fork length in mm.

7   **Table 5.F.4-1. Estimated Fork Lengths (mm) of an Individual Striped Bass by Age Class Used in**
8   **This Model**

Striped Bass Age (Year)	Fork Length (mm)			
	Spring	**Summer**	**Fall**	**Winter**
1	172	188	204	220
2	254	301	353	412
3	448	471	493	516
4	537	555	573	592
5	611	629	646	664
6	680	694	709	723
Source: Loboschefsky and Nobriga 2010. Note: For adult fish (age 3 and older), the lengths were averages of male and female size.				

10   The average early long-term and late long-term weekly water temperatures were derived from
11   model simulations of DSM2-QUAL averaged from stations in the north Delta. The temperatures
12   represent realistic water temperatures observed in the Sacramento River where the north Delta
13   intakes are proposed.

14   The weekly grams of juvenile Chinook salmon consumed per striped bass for all races then was
15   converted to race-specific weekly consumption estimates. The average weekly proportional
16   abundance for each race observed by USFWS Sacramento trawls (1994–2006) was multiplied by the
17   weekly grams of juvenile Chinook salmon consumed across all races to determine the weekly race-
18   specific grams consumed.

19   In order to convert the weight of juvenile salmon consumed by striped bass into the number of
20   salmon consumed, the weekly average fork lengths for each race from USFWS Sacramento trawls
21   (1994–2006) and the length-weight relationship developed by Petrusso and Hayes (2001) for
22   Chinook salmon in the Sacramento River were used:

23   $$W = 0.000004 \cdot \left(L^{[3.2578]} \right) ;$$ (Equation 4)

24   where W=Chinook salmon weight in g, and L=Chinook salmon fork length in mm.

25   After converting average weekly fork lengths (mm) to average weight (g), the model estimates of
26   weekly grams of juvenile Chinook salmon consumed for each race were divided by the weekly
27   average weight for individuals of each race to obtain the number of juvenile Chinook salmon of each
28   race consumed per striped bass.

1 Weekly race-specific consumption estimates then were summed across all weeks to calculate annual
2 consumption of Chinook salmon juveniles per striped bass for each race of salmon. The annual
3 number of Chinook salmon juveniles (C_{total}) consumed by the total number of striped bass at the
4 north Delta intakes (N_i) was calculated:

5
$$C_{total} = \sum_{i=1}^{age} N_i \times C_i \;;$$
(Equation 5)

6 where N_i is the number of striped bass per age class at the north Delta intakes and C_i is the
7 annual number of Chinook salmon juveniles consumed by an individual striped bass per age
8 class.

9 Loboschefsky and Nobriga (2010) provide a regression equation that predicts prey capture rates are
10 very low when prey length exceeds 0.47x of predator size. In this model it is assumed that when the
11 average length of emigrating juvenile salmon exceeds 0.47x the fork length of a striped bass, then no
12 predation loss would occur. The overall effect of this modification is relatively minor, because the
13 gape-size limitation for predation on juvenile salmonids would generally only affect relatively young
14 striped bass (i.e., age-1), which typically feed on invertebrates rather than fish.

15 In the model, the assumed striped bass density at the north Delta intakes ranged from
16 approximately 18 to 219 striped bass per 1,000 feet of screened intake, with a median value of
17 119 striped bass per 1,000 feet of intake. These estimates were based on fishery surveys of the GCID
18 fish screen evaluation program (Vogel 2008). The GCID fish screens are large, on-bank diversions
19 comparable to the diversions proposed as part of the conservation strategy.

20 To determine the striped bass densities per age class, the total number of striped bass were
21 multiplied by the proportion of striped bass in each age class (Table 5.F.4-2). The age distribution of
22 striped bass was from 36 years of historical survey data (data obtained from CDFW). While a
23 different age composition of striped bass might be expected to occur in association with the north
24 Delta intake, no data were available to develop a site-specific age composition.

25 **Table 5.F.4-2. Age Distribution of Striped Bass Used in the Model**

Age	Proportion
1	0.38
2	0.25
3	0.17
4	0.11
5	0.06
6	0.03

26

27 Finally, the annual percentage of Chinook salmon juveniles for each race consumed by the total
28 number of striped bass at the north Delta intakes was calculated by dividing race-specific annual
29 consumption by the average annual race-specific production estimated for brood years 2000
30 through 2009 (Table 5.F.4-3).

1   **Table 5.F.4-3. Summary of Data and Data Sources Used to Estimate Average Annual Production of**
2   **Total Juveniles and Smolts-Only Arriving at the Delta for Fall-Run, Winter-Run, Spring-Run, and Late**
3   **Fall–Run Chinook Salmon**

	Chinook Salmon Run				
Data Type	Winter	Spring	Fall	Late Fall	References
Total in-river escapement	7,634	8,924	293,393	16,214	California Department of Fish and Game GrandTab (March 2010b), 10-year average.
Pre-spawning mortality	5%	5.53%	42%	42%	Winter: Poytress and Carillo 2010. Spring: McReynolds and Garman 2008; McReynolds et al. 2005–2007. Fall, late fall: California Department of Water Resources 2001a.
Percent female	53.5%	54.6%	46%	46%	Winter, fall, late fall: Killam 2009. Spring: McReynolds and Garman 2008; McReynolds et al. 2005–2007.
Fecundity	3,859	5,300	4,500	5,800	Winter: Poytress and Carillo 2010. Spring: Cavallo et al. 2009. Fall: Lee and Chilton 2007. Late fall: Fisher 1994.
Egg to fry survival	33%	33%	33%	33%	Poytress and Carillo 2010.
Fry to Delta survival	53%	53%	53%	53%	U.S. Fish and Wildlife Service unpublished data.
Total juveniles reaching Delta	2,600,000	4,200,000	61,600,000	4,300,000	
Percent smolts entering Delta	82%	86%	52%	84%	U.S. Fish and Wildlife Service Sacramento trawls.
Total smolts reaching Delta	2,100,000	3,600,000	32,000,000	3,600,000	Note: Rounded to nearest 100 thousand.

4

5   ### 5.F.3.2.1.3   Differences from Original Loboschefsky and Nobriga (2010) Model

6   Loboschefsky and Nobriga (2010) provided prey-use regressions for small prey and large prey,
7   although only the large prey regression is used in this bioenergetics model. Loboschefsky and
8   Nobriga note that small salmon fry that wash down in the winter months are likely more accurately
9   modeled as small prey. Loboschefsky and Nobriga also calibrated their temperature data so that
10 they resulted in modeled striped bass growth rates that were within 0.1% of the observed annual
11 growth. In this bioenergetics model, the temperature data were derived from average weekly DSM2-
12 QUAL outputs at stations in the north Delta for both early long-term and late long-term.

13 ### 5.F.3.2.2   Fixed Predation Loss at North Delta Diversion Intakes

14 Another approach to assessing loss of emigrating Chinook salmon at the proposed north Delta
15 diversion is to assume a fixed loss rate of 5% per intake, applied iteratively for the three successive
16 intakes on the Sacramento River. This 5% loss term does not relate solely to the loss from predation,
17 but also includes mortality from impingement, injury or exhaustion.

1   While the 5% loss applies only to those fish that pass through this reach close to the screens, the
2   assumption here is that all of the fish are subject to this 5% loss. Because the BDCP intakes would be
3   located on-bank, only a proportion of the fish migrating down the lower Sacramento River would be
4   affected by altered hydrodynamics associated with the structures and active pumping. Furthermore,
5   the 5% loss assumption would apply only to that proportion of the Sacramento Basin population
6   that emigrates through the reach with the intakes. A subset of emigrating juveniles entirely bypass
7   the north Delta intakes by exiting the Sacramento River at the Fremont Weir and outmigrating via
8   the Yolo Bypass. Emigration through the Yolo Bypass will increase under BDCP operations (*CM2*
9   *Yolo Bypass Fisheries Enhancement*) because the Yolo Bypass would be inundated in all years except
10   critical water-year types.

11   The assumed 5% loss term is based on observations of acoustically tagged hatchery-raised juvenile
12   salmon released at the GCID screens (Vogel 2008). Approximately 5% of acoustically tagged juvenile
13   salmon migrating past the GCID fish screen were not detected downstream of the screen,
14   presumably because they were consumed by predators. There is uncertainty in this estimate of
15   predation loss because the lack of detections can also be due to malfunctioning of the acoustic tags
16   or receivers, or by juvenile salmon swimming upstream out of detection of the acoustic-tag receiver.
17   The GCID screen is the closest correlate in size to the proposed north Delta intakes, and the Vogel
18   (2008) study represents the only known observational study of Chinook salmon predation loss
19   associated with large water diversion structures in a lotic system.

20   There is considerable uncertainty in applying this loss term to the north Delta diversions because
21   the design and location of the GCID screen and the north Delta diversion are substantially different.
22   First, the GCID is located along a relatively narrow oxbow channel (about 10 to 50 meters wide)
23   while the north Delta intakes would be located on the much wider channel of the mainstem lower
24   Sacramento River (about 150 to 180 meters wide). The narrow oxbow channel may concentrate
25   salmon closer to the screens, exposing more of them to elevated predation loss. Juvenile fish
26   migrating down the lower Sacramento River would have the opportunity to be distributed across a
27   wider channel, so an appreciable proportion of outmigrating fish would not be in close proximity to
28   the north Delta intakes. Because the BDCP intakes would be located on-bank, only a proportion of
29   the fish migrating through this reach would be measurably affected by altered hydrodynamics
30   associated with the structures and active pumping. However, juvenile salmon tend to be distributed
31   towards areas with the highest flow velocities. The proposed intakes would be sited at locations to
32   achieve recommended sweeping velocities across the face of the screens, and thus may be near the
33   outsides of river bends.

34   Second, the estimates of predation loss at GCID are for a single large diversion intake, while there
35   are three north Delta intakes proposed under the Plan. Thus, while factors unique to the GCID
36   screen may increase predation loss estimates relative to the north Delta, the cumulative amount of
37   intake structure proposed under the Plan would be much larger than the GCID screen, increasing
38   exposure of juvenile salmon to screen-related impacts.

39   Fixed loss is a simplified approach that is likely to overestimate losses. For the purposes of this
40   analysis, it is assumed that all juvenile salmon migrating down the mainstem Sacramento River
41   would come in close proximity to the intakes, although there is high uncertainty with this
42   assumption. These results should be considered an upper bound for estimating potential loss.

1   ## 5.F.3.2.3   Pre-Screen Entrainment Loss at South Delta Facilities

2   Predation at the SWP and CVP south Delta facilities can be quite high, as inferred from pre-screen
3   entrainment losses, most notably in the CCF. Pre-screen loss rates for Chinook salmon and steelhead
4   are assumed to be 75% and 15% at the SWP CCF and CVP south Delta facilities, respectively
5   (Gingras 1997; Clark et al. 2009). As less water is exported at the south Delta under the conservation
6   strategy (due to availability of the new north Delta diversion facility), entrainment of covered fish
7   presumably will be reduced at the south Delta facilities. Under this analysis, it is presumed that
8   exposure to predation is proportional to entrainment of covered fish in the south Delta export
9   facilities.

10 The salvage density method represents the simplest model for estimating the total salvage that
11 occurs at the south Delta pumping facilities. Total monthly salvage numbers were calculated by
12 extrapolating estimates of the total number of fish salvaged based on a subsample that actually was
13 identified, counted, and measured. Salvage and loss data for analysis were normalized by measures
14 of annual population abundance in the year of entrainment for winter-run Chinook salmon (based
15 on juvenile production estimate), spring-run Chinook salmon (adult run size), delta and longfin
16 smelt (Fall Midwater Trawl). No normalization was undertaken for steelhead because there are no
17 suitable indices of annual abundance. Longfin smelt salvage loss was normalized using abundance
18 indices derived from Fall Midwater Trawl sampling since currently there are no metrics of actual
19 population levels. These data provided the basic estimates of fish density (number of fish salvaged
20 per unit of water exported) that subsequently were multiplied by simulated export data from
21 CALSIM modeling outputs. Further details are provided in Appendix 5.B, *Entrainment.*

22 However, it is acknowledged that the assumption of a linear relationship between entrainment and
23 flow may be an oversimplification given evidence of nonlinear relationships, as seen with delta
24 smelt (Kimmerer 2008). Thus, the salvage density method functions simply as a description of
25 changes in flow weighted by seasonal changes in salvage density of fish. For delta smelt,
26 entrainment estimates were based on the proportional OMR method (Kimmerer 2008).

27 ## 5.F.3.2.4   Predation Risk in Restored Habitats

28 Aquatic habitat restored under the conservation strategy (CM2, CM4, CM6 and CM7) will be used by
29 both native and nonnative species, including predatory fish. The degree to which these actions could
30 offset predation losses or contribute to predation risk will depend on the species-specific habitat use
31 patterns, abundance of predators, and predator consumption rates. Daily consumption rates of
32 native fish can be estimated from studies of fish predator stomach contents in the Delta (Stevens
33 1963; Stevens 1966; Thomas 1967; Nobriga and Feyrer 2007, 2008).

34 A quantitative assessment is difficult because data are lacking on predator densities associated with
35 different restored habitats. Predation risk could be estimated with data on predatory fish densities
36 in similar habitats, consumption rates of juvenile salmonids, and the amount of restored habitat. The
37 USFWS sampled Liberty Island by gill netting and beach seining and documented densities of
38 predators (largemouth bass, striped bass, and pikeminnow combined). However, these estimates
39 have a degree of uncertainty associated with them depending on assumptions of habitat availability,
40 value (e.g., depth, vegetation), and use by different species.

41 To understand the overall effect of habitat restoration on covered fish species, these estimates of
42 predation would have to be placed in the context of predation under existing conditions, numbers of
43 covered species with and without restoration, and proportion of population lost to predation.

1   ### 5.F.3.2.5   Effects of Predator Reduction

2   The effects of predator reduction efforts (*CM15 Localized Reduction of Predatory Fishes*) are assessed
3   qualitatively, using assumptions of removal efficiencies and information from a fish removal
4   experiment in the Delta (Cavallo et al. 2012), as well as control programs implemented on other
5   systems such as the Columbia River (Porter 2010) and Colorado River (Mueller 2005). These studies
6   illustrate the complexities of incorporating predator removal practices in an open aquatic ecosystem
7   like the Delta.

8   ## 5.F.3.3   Invasive Mollusks Analysis

9   Changes in water operations (*CM1 Water Facilities and Operation*), open-water area (*CM4 Tidal*
10   *Natural Communities Restoration*), and the amount of freshwater flow through the Delta may shift
11   the estuarine salinity gradient, and therefore the spatial occurrence of *Potamocorbula* and *Corbicula*
12   (Peterson and Vayssieres 2010). *Potamocorbula* larvae require salinities greater than 2 ppt for
13   successful settlement (Nicolini and Penry 2000), while *Corbicula* require salinities less than 2 ppt
14   (Aguirre and Poss 1999). Because it has spread rapidly throughout the brackish transition zone of
15   the estuary since its introduction in 1986, *Potamocorbula* has become a major management concern.

16   The potential effects of CM1 operations on habitat for *Potamocorbula* in the Suisun Bay and West
17   Delta subregions of the Plan Area was assessed for the full decision-tree range, from Evaluated
18   Starting Operation (ESO) that includes the Fall X2 requirement, to a scenario that does not
19   implement the Fall X2 requirement but does meet State Water Resources Control Board water right
20   Decision 1641 (D-1641) requirements (similar to Alternative 1A [ALT1_ELT and ALT1_LLT]), using
21   CALSIM modeling data for monthly X2.[1] The abundance of *Potamocorbula* recruits can be related to
22   X2 because bottom salinity determines the success of settling larvae (Thompson and Parchaso 2010:
23   10). The downstream limit of the Plan Area is at Benicia, around 56 km from the Golden Gate Bridge,
24   and salinity in this area is suitable for *Potamocorbula* in all years (see Figure 4 of Thompson and
25   Parchaso 2010). The area of suitable habitat for *Potamocorbula* for each modeling scenario (EBC1,
26   EBC2, EBC2_ELT, EBC2_LLT, ESO_ELT, and ESO_LLT [EBC = existing biological conditions; ELT =
27   early long-term; LLT = late-long term]) in each month of the CALSIM modeling period was estimated
28   as the area between km 56 (Benicia) and X2 (lagged by one month because CALSIM output provides
29   X2 for the end of the previous month).

30   Estuarine area was based on the estimates by Jones & Stokes Associates (1995) (Figure 5.F.4-3),
31   with the small areas of restored habitat in the West Delta ROA added to results for the ESO scenarios
32   as necessary based on X2. Monthly estimates of area were multiplied by the proportion of overall
33   recruitment in each month, based on the summer-fall recruitment pattern observed in the West
34   Delta subregion near Chipps Island (Figure 5.F.4-4) (Thompson and Parchaso 2010: 33).

35   The final index of habitat suitability was the total sum of the area (n square kilometers [km^2]) of
36   habitat in each water year. October through December were included in the previous water-year
37   designation in order to capture both the annual pattern of *Potamocorbula* recruitment (which
38   overlaps water years) (Figure 5.F.4-4) and the fact that water management for Fall X2 in October
39   through December depends on the water-year designation from the preceding water year. The

[1] X2 represents the 2% isohaline, given as the distance upstream from the Golden Gate Bridge to the point
where daily average salinity at 1 meter from the bottom is 2 ppt (Jassby et al. 1995).

1   habitat area estimate for the final water year (2003) was excluded because the full July through
2   December *Potamocorbula* recruitment period was not modeled for this year.

3   This approach does not account for factors such as substrate nor the density of existing benthic
4   populations, which may influence the potential for occurrence in specific regions of the Plan Area.
5   Also, successful recruitment could occur upstream of X2 if salinity is above 2 ppt for sufficient time
6   to allow successful settlement and recruitment, for example, at a sub-monthly time scale not
7   captured in the CALSIM modeling. However, these factors apply to EBC and ESO scenarios and so are
8   assumed not to bias the analysis.
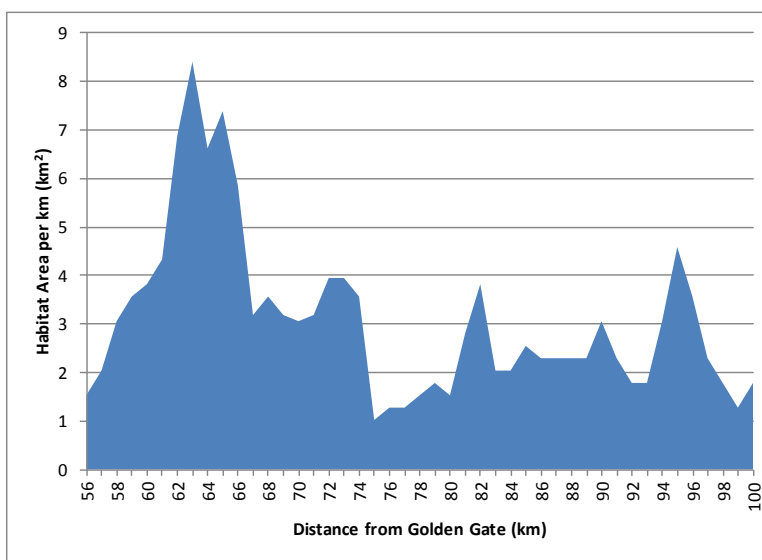
9
10   Source: Jones & Stokes Associates 1995: Appendix A, Figure 9).

11   **Figure 5.F.4-3. Habitat Area (km^2) at Each Kilometer from the Golden Gate Bridge in the Suisun Bay**
12   **and West Delta Subregions of the Plan Area**
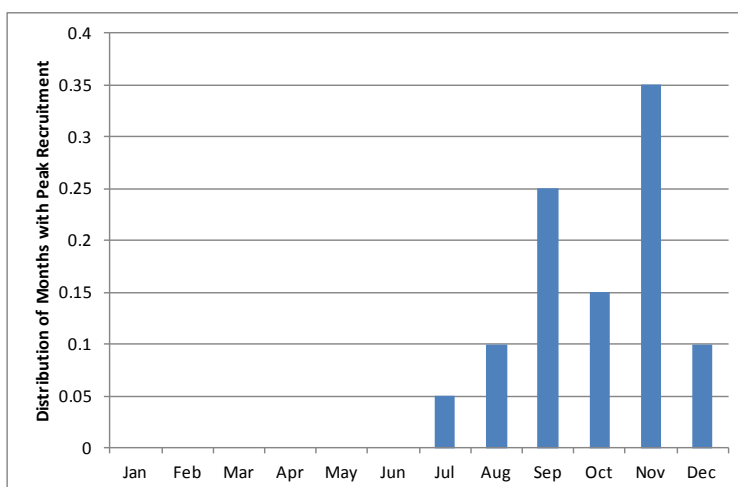
13
14   Source: Thompson and Parchaso 2010:33.
15   **Figure 5.F.4-4. Distribution of Months with Peak *Potamocorbula* Recruitment in the West Delta**
16   **Subregion (Chipps Island Channel)**

5.F.3.4 *Microcystis* Analysis

Water temperature, residence times, freshwater flows, turbidity, salinity, and nutrients all affect the rate of proliferation of *Microcystis* (Lehman et al. 2010). Changes in water operations (CM1) and tidal restoration (CM4) may increase residence time and reduce the amount of freshwater flow through the Delta, affecting the rate at which *Microcystis* can accumulate and cause blooms. Additionally increased temperature resulting from climate change could facilitate *Microcystis* blooms. The potential effect of the ESO on these factors was evaluated for subregions of the Plan Area and during the seasons with greatest potential for blooms (June to November). Residence time was assessed based on DSM2 modeling data (Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*).

5.F.4 Invasive Aquatic Vegetation

5.F.4.1 Ecological Effect Pathways

By 1995, about 25 invasive plant species had been tallied in the San Francisco Bay/Sacramento–San Joaquin River Delta (Bay-Delta) (Cohen and Carlton 1995). A later review (Light et al. 2005) listed 69 nonnative aquatic plants known from the Delta, including riparian and wetland plants, as well as fully aquatic species, dividing them into definite and probable invaders. Of great concern in the Delta is the presence of IAV. It has the ability to significantly alter habitat conditions for aquatic animals, including covered fish species, by changing the hydrologic regime, sedimentation, water quality, and nutrient cycling.

The term *IAV* is used to describe invasive nonnative aquatic plant species that have the capacity to grow and spread rapidly. IAV includes both SAV (plants that root in the sediment and remain below the water surface) and FAV (plants that float freely on the water surface). The term *SAV* includes all submersed plants, native as well as nonnative, and similarly, *FAV* includes all native and nonnative floating aquatic plants.

IAV impairs covered fish habitat via several mechanisms (discussed in Section 5.F.4.2.1, *Conceptual Model*, and Chapter 3, Section 3.4.13.1, *Problem Statement*).

- Alters habitat by reducing water flow, thereby decreasing turbidity.

- Provides suitable habitat for predatory fish that prey on covered fish species.

- Physically impairs access and displaces native fish from shallow-water habitats.

- Alters physical and chemical habitat attributes such as light penetration, dissolved oxygen (DO), pH, and nutrient concentrations.

- Displaces native plants that would otherwise create physical structure and a biological environment that supports native fish species (e.g., aquatic habitat dominated by native plants instead of IAV would enhance the diversity of native invertebrates that provide a forage base for native fish).

A significant portion of the Delta's 54,858 acres (based on the DBW waterway acreage) of aquatic habitat provide suitable conditions for the rapid spread of IAV, including shallow, warm waters and an almost year-round growing season. Restoration of aquatic habitats under the Plan has the potential to create additional suitable habitat that could be invaded by IAV.

1   Two species, *Egeria densa* and *Eichhornia crassipes* (water hyacinth), have expanded greatly over
2   the past decade have received the bulk of the attention to date in terms of ecological research,
3   surveys, and control efforts. Both species have no known natural predators or parasites in the Delta
4   environment. Because of the problems these two species create for navigation, the DBW was
5   mandated legislatively to control both egeria and water hyacinth in the Delta and its tributaries. In
6   tandem with implementing control treatments (begun in 2001 for egeria and 1983 for water
7   hyacinth), DBW has been researching and developing methods and protocols for chemical, and to a
8   lesser extent mechanical and biological, treatments and supporting research on the biology of these
9   species and the effects of control treatments in the Delta. Other IAV species that are already present
10 in the Delta or elsewhere in California have the potential to become invasive in the Delta. Egeria,
11 water hyacinth, and other potential IAV species in the Delta are discussed below.

12   5.F.4.1.1   Brazilian Waterweed (*Egeria*)

13 Brazilian waterweed, also known as *Egeria*, is a submerged aquatic perennial plant that grows
14 rooted in sediment in shallow, freshwater areas of the Delta. The plant forms very dense stands (it
15 can also be found as free-floating fragments) and is now the most abundant component of SAV in the
16 Delta, displacing most of the native SAV (Santos et al. 2011). It typically grows at depths up to about
17 2 to 3 meters in the Delta, but has the potential to grow as deep as 6 meters in clear water
18 (Anderson and Hoshovsky 2000); it occurs in freshwater areas, primarily upstream from Antioch.
19 *Egeria* grows very rapidly under good conditions such as those that occur in the shallow-water areas
20 of the Delta. Recent research on the ecology of *Egeria* has shown that climate and temperature
21 conditions in the Delta are ideal for year-round growth (Pennington and Sytsma 2009). Under ideal
22 experimental conditions, a relative growth rate (RGR) of 6.3% per day, equivalent to a biomass
23 doubling time of 12 days, has been recorded (Pistori et al. 2004), making this species one of the
24 fastest-growing aquatic plants. In 2006, under field conditions in the Delta, RGRs as high as 2.42%
25 per day were measured (Spencer and Ksander 2005). Reproduction in the Delta is solely by
26 vegetative fragmentation—only male plants are present in the United States, so no seed is produced.

27 In 2006, DBW estimated that approximately 11,500 to 14,000 acres were infested, and the weed was
28 spreading at an estimated rate of 10 to 20% per year, potentially doubling in acreage every 10 years
29 based on observed expansions at sites where *Egeria* was present (California Department of Boating
30 and Waterways 2006). More recent analyses based on aerial imagery analysis estimated
31 approximately 10,000 acres in June 2007, equivalent to approximately 18% of the Delta's
32 waterways. (Ustin 2008), and confirmed the overall rate of increase was similar to that estimated by
33 DBW in 2006.

34 Control of *Egeria* is difficult and challenging for several reasons:

35 ●   The species exhibits high growth rates and large amounts of biomass accumulation.

36 ●   Mechanical removal fragments the plants, the fragments disperse and readily multiply as new
37   plants, and disposal of harvested plants is difficult.

38 ●   Herbicides effective at killing the plants have risks associated with their use, but to date, the
39   only practical and successful large-scale control measure has been herbicide application.

40   5.F.4.1.2   Water Hyacinth

41 Water hyacinth is a floating perennial aquatic plant that inhabits calm backwater areas or areas with
42 low velocities and is the dominant component of FAV in many areas of the Delta. Water hyacinth

1   proliferates during the warmer summer months and dies back during the winter. Reproduction is by
2   seed and vegetatively, by production of stolons and budding. Seeds sink into the sediment and can
3   remain dormant for 15 to 20 years. Doubling times in surface area covered of 6 to 15 days have been
4   reported (Harley et al. 1996). Because the plant is not rooted in the substrate, its distribution is
5   influenced by water currents and prevailing wind. During the spring and summer, the dominant
6   westerly winds often hold the plants against the lee shorelines or in backwaters of the Delta. In off-
7   channel and backwater sites, hyacinth mats can become dense enough to close off open water
8   completely. In the fall, when the seasonally predominant westerly winds decline, mats of hyacinth
9   will float out into the main channels where they are moved about by the river and tidal currents.

10 Water hyacinth began to spread into the Delta in the 1940s and 1950s, and covered 1,000 acres by
11 1981 (California Department of Boating and Waterways 2009). Since then, cover has been as high as
12 2,500 acres, but the acreage is now much reduced, and the most recent estimate, from June 2007, is
13 139 acres (Ustin 2008).

14 ## 5.F.4.1.3   Other New and Potential Invasive Aquatic Vegetation

15 Several potential IAV species are already present in the Delta, for example Eurasian water milfoil
16 (*Myriophyllum spicatum*), Carolina fanwort (*Cabomba caroliniana*), and curly pondweed
17 (*Potamogeton crispus*) (Santos et al. 2009).

18 A very recent invader, South American spongeplant (*Limnobium laevigata*) appeared in the Delta in
19 2007 and was documented again in 2009-2010, when it appears to have gained a foothold
20 (California Department of Food and Agriculture 2011; Anderson and Akers 2011). This species is
21 considered a serious threat to the Delta. Responsibility for its control initially was given to California
22 Department of Food and Agriculture's (CDFA's) Hydrilla Eradication Program, which aggressively
23 targets new infestations with the goal of eradication (Akers 2010). Under recent legislative action,
24 Assembly Bill 1540 added spongeplant to DBW's mandated list of aquatic weeds to control. Overall,
25 South American spongeplant is potentially a more serious threat than water hyacinth. It also has a
26 high growth rate and spreads rapidly, but the individual plants are much smaller than water
27 hyacinth and can be transported easily with the water currents. Additionally, it produces abundant
28 seeds that can remain dormant in sediment. Management actions that include vigilance and early
29 eradication before the plant becomes established are vital (Akers 2010).

30 Additional invasive aquatic species that have been detected elsewhere in California but are not yet
31 known to occur in the Delta are giant salvinia (*Salvinia molesta*) and hydrilla (*Hydrilla verticillata*)
32 (San Francisco Estuary Institute 2003). The notorious hydrilla occurs in Clear Lake, within the
33 watershed of the Delta, and is considered such a high threat that it is targeted by CDFA for complete
34 eradication.

35 Over the 50-year life of the conservation strategy, it is likely that nonnative aquatic species would
36 continue to be introduced as they have in the past (Cohen and Carlton 1995), and it is likely that
37 some would be invasive and could spread rapidly to become problematic, as *Egeria* and water
38 hyacinth already have. The introduction of new species is a continuing process, as shown by the
39 dates of introduction of more than 70 nonnative plant species in the Delta (Light et al. 2005). Figure
40 5.F.5-1 shows graphically that the rate of invasion by nonnative plant species has been relatively
41 constant since records began and shows no sign of decreasing.
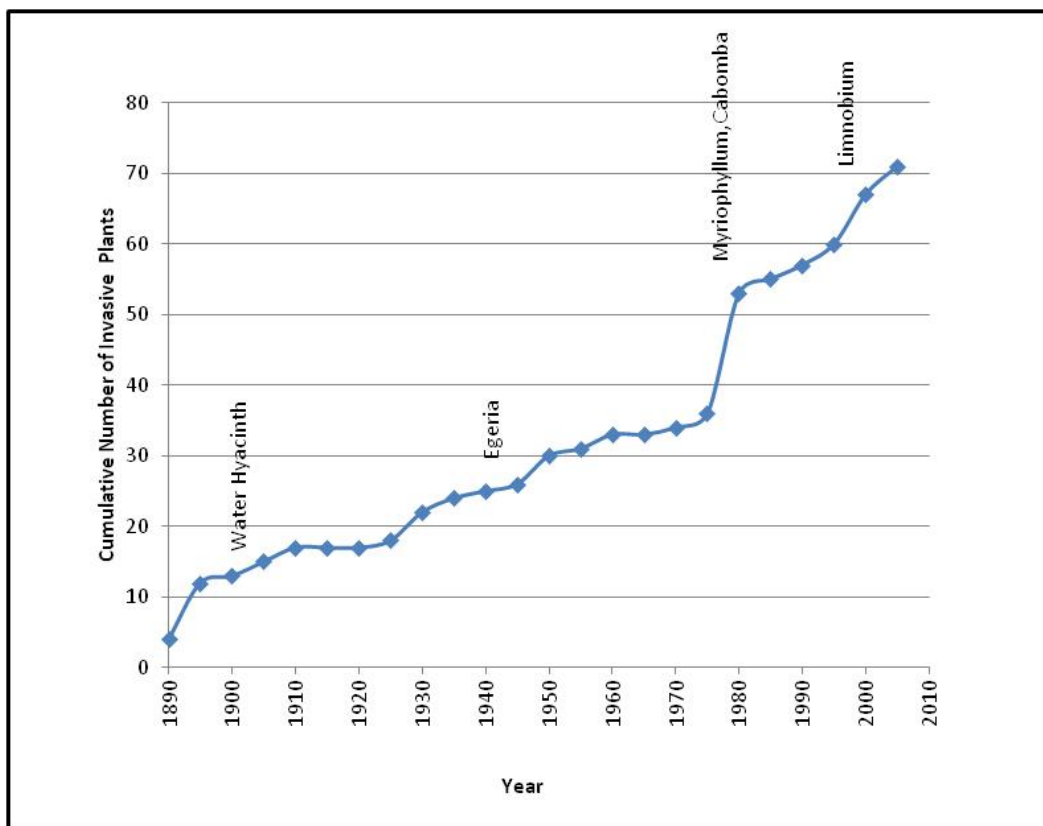
Source: Data from Light et al. 2005.

Figure 5.F.5-1. Cumulative Number of Nonnative Plant Species in the Delta Region

Summer residence time is projected to increase because of climate change and the water operations under ESO (Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*). Likewise, water temperatures are projected to increase because of climate change, but not water operations. These changes may increase the potential for growth of IAV in areas with suitable environmental conditions and suitable salinities (Cache Slough, West Delta, North Delta, South Delta, and East Delta subregions).

The California Invasive Plant Council (Cal-IPC) is working to develop climate suitability modeling and range change maps for invasive plants listed in their inventory (California Invasive Plant Council 2012) that could help to predict which plant species could establish and spread in the Delta; however, distribution models are not yet available for IAV species.

5.F.4.2   Conceptual Models and Hypotheses

5.F.4.2.1   Conceptual Model

The conceptual model for IAV (including both SAV and FAV) is based on information in the scientific literature and the draft DRERIP aquatic vegetation growth conceptual model (Anderson 2008). The conceptual model includes the primary drivers, stressors, and their effects (linkages) related to IAV and is a useful guide for generating hypotheses, highlighting uncertainties, predicting outcomes, and directing research (Figure 5.F.5-2). The model is qualitative because quantitative information on the relationships between drivers and effects is largely lacking. The Delta is a complex interconnecting series of sloughs, channels, and basins, with salinities and flow regimes that vary in space and time,

1   both short-term and long-term. This variability introduces uncertainty and unpredictability in
2   evaluating effects. Recent and ongoing research in the Delta is beginning to address quantitatively
3   some of the drivers and stressors and their effects on IAV, and on the responses of IAV species to
4   environmental variables. The following discussion highlights these studies.

5   The primary drivers affecting establishment, growth, and spread of IAV are salinity, turbidity,
6   nutrients, flow regime, and light. In terms of effects on covered fish species and ecosystem change, a
7   primary focus has been on the interaction between water flow, turbidity, and IAV. A second set of
8   interactions exists between the presence of invasive SAV and changes in the fish population
9   composition. The following sections discuss the interactions between IAV and aquatic organisms
10   and water quality.
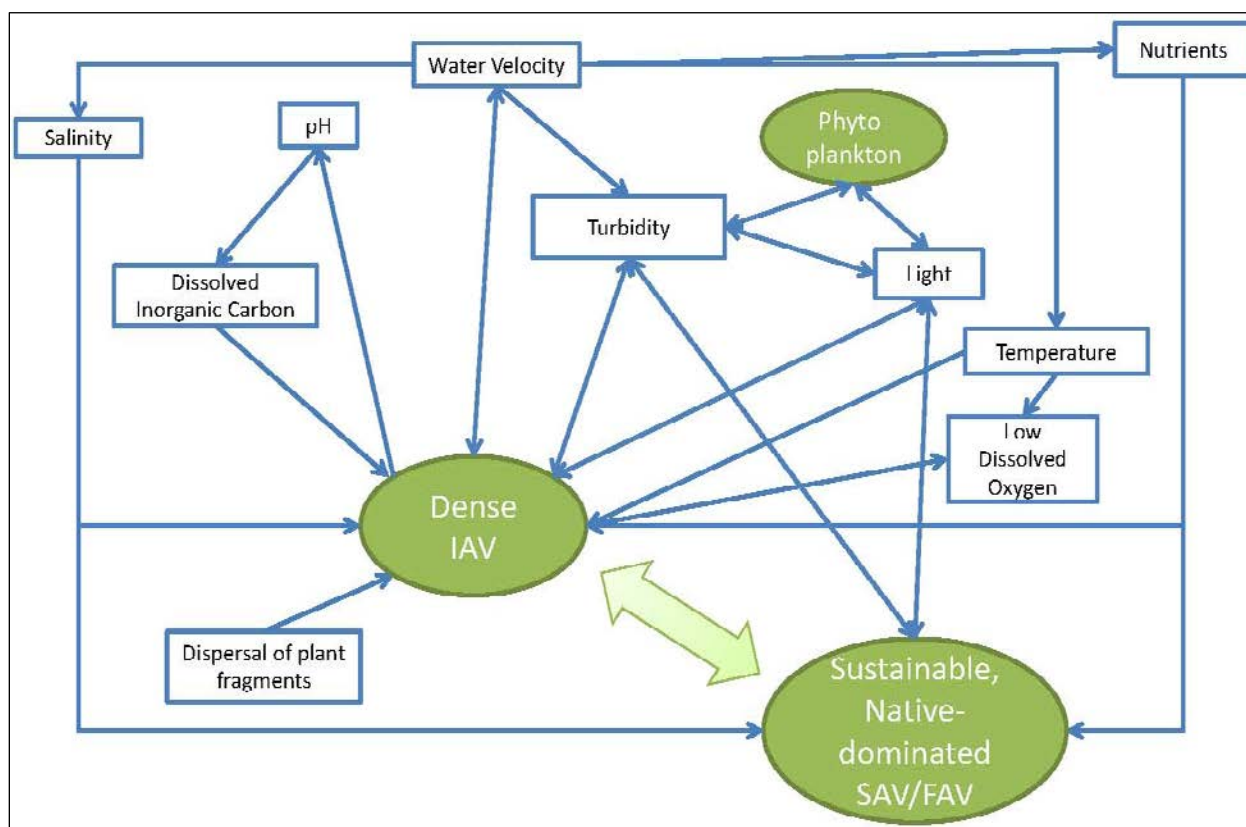
11

12   **Figure 5.F.5-2. Conceptual Model of Invasive Aquatic Vegetation in the Delta**

13   ### 5.F.4.2.1.1   Habitat for Nonnative Predatory Fish

14   The rapid expansion of IAV, especially *Egeria*, has caused changes in the physical habitat and water
15   quality that have displaced native fish and favor a foodweb more suitable for nonnative centrarchid
16   fish, such as largemouth bass. Over recent years coincident with this expansion, there has been an
17   increase in the abundance of nonnative fish, including predatory species, and a decline in native fish,
18   including covered species (Brown and Michniuk 2007). Largemouth bass are the most abundant and
19   effective predator in the areas with high SAV cover (Grimaldo et al. 2004; Nobriga and Feyrer 2007),
20   and it is hypothesized that SAV provides habitat for largemouth bass that prey on native fish (Brown
21   2003; Nobriga et al. 2005). The effects of nonnative predatory fish on covered species are discussed
22   in further detail in Section 5.F.5, *Fish Predation*.

1   ## 5.F.4.2.1.2   Habitat Alteration by Invasive Aquatic Vegetation

2   Invasive SAV can act as an ecosystem engineer, defined as "organisms that directly or indirectly
3   modulate the availability of resources to other species by causing physical state changes in biotic or
4   abiotic materials" (Jones et al. 1994). Specifically, IAV, and especially invasive SAV, fundamentally
5   alters the aquatic environment by increasing sedimentation and reducing turbidity. Surface cover of
6   water hyacinth also impedes water flow and causes sediment to settle. The relationship between
7   turbidity and IAV therefore is modeled as a positive feedback loop. Large dense stands of SAV
8   reduce flow velocity and decrease water turbulence, reducing resuspension of sediments and
9   thereby reducing turbidity (Yarrow et al. 2009; Hestir et al. 2010a, 2010b). The decreased turbidity
10   increases the light penetration through the water column and increases SAV growth. This positive
11   feedback may be an important factor contributing to the ecological regime shift (Scheffer and
12   Carpenter 2003) that has occurred in the Delta from a turbid phytoplankton-dominated system to
13   the current clear-water SAV-dominated state of the Delta (Baxter et al. 2010). This effect is well
14   known to occur in shallow freshwater lakes, but it is uncertain how strong this feedback would be in
15   the Delta because of high inputs of mineral sediment and temporal and spatial variations in flow,
16   turbidity, and SAV distribution (Hestir et al. 2010a).

17   ## 5.F.4.2.1.3   Physical Displacement of Native Fish Species

18   Dense stands of invasive SAV physically occupy nearshore habitat and thereby displace larval and
19   juvenile smelt and juvenile salmonids that otherwise may have inhabited the shallow-water habitat.
20   In particular, the dense wall of *Egeria* that grows along channel margins in the Delta prevents
21   juvenile native fish from accessing their preferred shallow-water habitat (California Department of
22   Boating and Waterways 2006). Dense SAV also could produce a biological barrier between
23   nearshore open waters and tidal wetlands (Brown 2003) or along migration routes through the
24   Delta (California Department of Boating and Waterways 2006; National Marine Fisheries Service
25   2007; Baxter et al. 2010) and block rearing habitat for juvenile salmon and splittail (Interagency
26   Ecological Program 2008).

27   The observed decline in delta smelt occurrence in areas where *Egeria*-dominated SAV has become
28   established (Nobriga et al. 2005) may be related, in part, to the physical displacement of delta smelt
29   from spawning areas. Delta smelt are thought to scatter their eggs over open substrate (Mager et al.
30   2004), probably spawning on or over sandy substrates at subtidal elevations (Moyle 2002). Specific
31   delta smelt spawning sites have never been documented in the wild, and spawning migrations are
32   poorly understood, but it is generally thought that spawning occurs in shallow, low-salinity
33   upstream areas with sand or gravel substrate on which to deposit adhesive eggs (Moyle et al. 2004).
34   Suitable habitat could occur in Cache Slough or in shallow shoals in the Deep Water Ship Channel.
35   Invasive SAV has been documented physically occupying both the open water column over potential
36   spawning habitat and the substrate itself. As a result, spawning delta smelt are displaced from these
37   areas. Additionally, invasive SAV causes fine material to settle out of the water and accumulate,
38   which could reduce the amount of suitable substrate for spawning if the accumulated material is
39   finer-grained than the sandy substrate that may be used by delta smelt for spawning (Bennett
40   2005).

41   Longfin smelt are known to spawn in freshwater portions of the Delta (Baxter et al. 2010), and most
42   spawning is believed to take place in the Sacramento River near or downstream of Rio Vista, and
43   downstream of Medford Island on the San Joaquin River (Wang 1986). General spawning areas for
44   both delta smelt and longfin smelt have been inferred based on the capture location of small larvae

1   during winter/spring larval surveys. If the spawning areas of longfin smelt overlap SAV infested
2   areas, the smelt may be displaced from those areas.

3   ### 5.F.4.2.1.4   Water Quality

4   IAV can alter water quality, including parameters important for covered fish species such as DO,
5   water velocity, turbidity, and nutrient flux and balance that may affect planktonic foodweb
6   dynamics. In turn, IAV is influenced by Delta water quality conditions and trends, such as water
7   temperatures, salinity, and nutrient enrichment.

8   **Salinity**

9   Salinity is an important factor controlling invasive SAV distribution and growth in the Delta. Salinity
10   limits the spread of *Egeria* westward into the estuary and is probably a major factor in its absence
11   from Suisun Marsh*. Egeria* in its native range is a freshwater plant and tolerates salinity of up to
12   5 ppt although growth rate is reduced at this level (Hauenstein and Ramirez 1986). In laboratory
13   conditions shoots continued to grow at salinity of 6 ppt, although growth did show a decrease with
14   increasing salinity (Obrebski and Booth 2003). Hauenstein and Ramirez (1986) found no growth of
15   roots or stems at salinity greater than 10 ppt, suggesting that complete suppression of *Egeria* would
16   require salinity levels approaching 10 ppt.

17   Different SAV and FAV species respond differently to different salinities. Another potentially
18   invasive SAV species, Eurasian water milfoil, appears to be more tolerant of salinity, requiring
19   concentrations over 13 ppt for toxic effects in the laboratory (Haller et al. 1974), and in Delta
20   surveys it was positively associated with salinity (Santos et al. 2011). Extensive stands of native sago
21   pondweed occur in the West Delta and Suisun Bay, suggesting that this species is more tolerant of
22   salinity than *Egeria* (Rubissow Okamoto 2012; Boyer 2012). Water hyacinth is much more sensitive
23   and cannot tolerate salinity above 2.5 ppt (Haller et al. 1974).

24   **Temperature**

25   Warm water and air temperatures in the Delta are conducive to year-round growth of IAV species.
26   Winter temperatures low enough to limit growth are rare; although the occasional frost can damage
27   water hyacinth leaves and cause dieback, freezing temperatures are seldom sustained long enough
28   to kill plants*. Egeria* does not show winter dormancy in the Delta (Pennington and Sytsma 2009).

29   The effect of IAV cover and biovolume water temperature has not been quantified in the Delta, but it
30   is likely that the reduced water flow caused by dense SAV cover could increase water temperature
31   locally, which in turn would enhance growth of SAV. This can lead to vertical stratification of
32   temperature in the water column (Grimaldo and Hymanson 1999; Wilcox et al. 1999). This effect
33   may be offset to an unknown extent by the shading effect of SAV on the water column, which could
34   decrease water temperatures. If dense IAV limits water flow between open water areas and the IAV
35   stands, horizontal temperature gradients may develop (Stacey 2003).

36   **Biochemistry**

37   The role of nutrient enrichment in the high growth rates and spread of IAV is unclear. Potential links
38   between IAV and nutrient inputs in the Delta are the subject of ongoing studies and require further
39   research.

1 Alkalinity is important for some aquatic plants, especially those like *Egeria* that can assimilate
2 bicarbonate as an alternative source of inorganic carbon when carbon dioxide is limiting, allowing
3 high photosynthetic rates, and hence, growth rates (Kahara and Vermatt 2003; Sousa 2011). High
4 photosynthetic rates, in turn, deplete carbon dioxide and increase pH to high levels (Sand-Jensen
5 1983). Elevated bicarbonate is known to cause long-term stimulation of growth rates in *Egeria* and
6 similar species in laboratory and field experiments (Madsen and Sand-Jensen 1987, 1994).

7 In the laboratory, *Egeria* grew significantly better at high alkalinity (500 micromoles per liter
8 [μM/L]) than at low alkalinity (100 μM/L), alkalinity values similar to those observed in the field
9 (Freitas and Thomaz 2011). The observation that *Egeria* grew faster at higher alkalinity led Freitas
10 and Thomaz (2011) to suggest that organic carbon may limit *Egeria* growth, and that therefore
11 nitrogen and phosphorus may not be limiting and may be secondary in controlling growth, leading
12 to the further suggestion that reducing nitrogen and phosphorus may not be effective in reducing
13 *Egeria* growth and spread.

14 However, elevated levels of ammonium and other nutrients may benefit IAV species such as water
15 hyacinth (Reddy and Tucker 1983) and *Egeria* (Feijoó et al. 2002). Studies on *Egeria* in its native
16 range have shown that biomass is positively correlated with ammonium in the water (Feijoó et al.
17 1996) and that *Egeria* absorbed more nitrogen from the water when nitrogen was present as
18 ammonium than when it was present as nitrate (Feijoó et al. 2002).

19 Dense IAV also can cause biogeochemical changes in water quality. For example, high levels of
20 photosynthesis increase pH, leading to an increase in the toxic form of ammonia (NH_3) and an
21 increase in the phosphate flux from sediments.

22 **Dissolved Oxygen**

23 Dense mats of water hyacinth produce large amounts of dead vegetative matter that decrease the
24 DO level under the mats as they decay, and respiration of the high plant biomass causes nighttime
25 depletion of DO (Penfound and Earle 1948; Ultsch 1973; Center and Spencer 1981), especially at
26 high water temperatures (National Marine Fisheries Service 2006). This effect may be exacerbated
27 by lack of water flow or water-air interface mixing, leading to zones of hypoxic or anoxic water
28 conditions (National Marine Fisheries Service 2006). In the Delta, beneath water hyacinth mats,
29 levels have been recorded below 5 milligrams per liter (mg/L) to as low as 0 mg/L, below
30 sustainable levels for fish (Toft 2000). These extremely low DO levels also may explain the absence
31 of epibenthic amphipods and isopods beneath the water hyacinth canopy (Toft 2000). Dense *Egeria*
32 also may deplete DO levels at night (Wilcox et al. 1999).

33 ## 5.F.4.2.1.5   Water Velocity/Flow Regime

34 Flow regime is an important influence on distribution of IAV. In the Delta, water velocity influences
35 IAV distribution, limiting it to channel margins, shallow basins, and slow-moving channels. High
36 water velocity inhibits SAV growth by physically washing plants out of the sediment, and perhaps
37 also by scouring out the finer sediment in which SAV root. Similarly, water and wind currents
38 control the distribution of FAV, especially the larger plants like water hyacinth. In a recent study,
39 Hestir and coauthors (2010a) tested for an annual maximum channel water velocity critical to
40 *Egeria*-dominated SAV in the Delta, and found that the maximum separation between low and high
41 areal coverage of SAV was at a threshold velocity of 0.49 meter per second (m/s) (1.61 fps),
42 indicating that *Egeria* establishment is limited at that threshold velocity. As stands of IAV expand in
43 an area, its dense structure further reduces local water velocity.

1   **5.F.4.2.1.6   Changes in Turbidity**

2   Dense stands of *Egeria*-dominated SAV reduce water turbidity by filtering sediment from the water
3   column (Brown and Michniuk 2007; Yarrow et al. 2009; Hestir et al. 2010a). Field experiments have
4   shown that SAV can significantly reduce turbidity. For example, in one experiment using agricultural
5   drainage water, channeling water through reservoirs stocked with SAV demonstrated that SAV
6   reduced turbidity by up to 30% (Reddy et al. 1983).

7   On a landscape level, recent research has shown that turbidity in the Delta has been declining
8   gradually for several decades, and decreased in a step-wise manner in 1999 (Schoellhamer 2011).
9   Over the same period, IAV, especially *Egeria*-dominated SAV, was increasing. Historical turbidity
10   data and estimates of SAV cover from 1975 to 2008 were analyzed to reveal any relationship over
11   time between increasing SAV cover and decreasing turbidity across the Delta (Hestir et al. 2010b).
12   The analysis showed that SAV cover explains an estimated 21 to 70% of the trend of decreasing
13   turbidity, and turbidity declines attributable to SAV cover were greater as SAV cover increased
14   (Hestir et al. 2010b).

15   While no field experiments in the Delta directly demonstrate this causal mechanism, turbidity
16   measurements before and after a large-scale herbicide treatment at Franks Tract illustrate this
17   concept. Franks Tract is a 3,000-acre shallow-flooded island in the central Delta that supported
18   extensive areas of dense *Egeria*. In 2007 and 2008 DBW treated a total of 2,570 acres of *Egeria*.
19   *Egeria* cover was reduced by 1,500 acres (47%) in 2007 (Ustin 2008; Santos et al. 2009), and *Egeria*
20   biovolume was significantly reduced (Ruch and California Department of Boating and Waterways,
21   Aquatic Weed Unit 2006). Additional treatment in 2008 yielded a further 50% reduction (Santos et
22   al. 2009). The extensive *Egeria* treatments in 2007-2008 resulted in the lowest biovolume and cover
23   of *Egeria* in several years (California Department of Water Resources 2008; Ustin 2008).

24   Turbidity and SAV cover were measured at Holland Cut near Bethel Island and at False River near
25   Oakley immediately before and after the *Egeria* treatments. (Hestir et al. 2010a). Between 2006 and
26   2007, the data were equivocal, showing a marked reduction in SAV but no corresponding increase in
27   turbidity. However, between 2007 and 2008, there was a further reduction in SAV cover of an order
28   of magnitude and a corresponding increase in turbidity, from 5.1 Nephelometric turbidity units
29   (NTU) to 8.3 NTU. This observation is an indication that SAV removal could result in a small local
30   increase in turbidity. However, the resulting turbidity increase did not reach the levels critical for
31   delta smelt; for example, it does not reach the 12 to 15 NTU level that cues spawning migration
32   (Grimaldo et al. 2009a).

33   Longer-term continuous monitoring of turbidity in the tidal channels connected to Franks Tract
34   began in fall 2007 (California Department of Water Resources 2008). In the winter of 2007-2008,
35   several severe turbidity events were detected at the Holland Cut turbidity monitoring station, with
36   turbidity exceeding 12 NTU. Some were triggered by strong winds that mixed bottom sediments in
37   Franks Tract. Several factors were identified that could have contributed to these turbidity events,
38   and it was concluded that all of these factors can be affected by *Egeria* (California Department of
39   Water Resources 2008). Unfortunately, the turbidity monitoring stations were established in fall
40   2007, so there are no comparative data from previous years. Turbidity measurements in 2008 and
41   2009 showed lower daily turbidity averages and fewer pulses of severe turbidity than were
42   recorded in 2007-2008 (California Department of Water Resources 2008). This suggests that the
43   increase in turbidity post-treatment may be short-term, as the sediment accumulated over several

1　years by *Egeria* may be washed out in a short time period, perhaps even over the course of one
2　winter's storms.

3　Delta smelt are positively associated with highly turbid water (Grimaldo et al. 2009a). The areas
4　with the greatest extent of invasive SAV in the Delta are the channels and flooded islands of the West
5　and South Delta subregions such as Frank's Tract, Mildred Island, Big Break, Sherman Lake, and
6　OMR. These areas generally also have the highest water clarity in the Delta and now are used less
7　often by delta smelt than they were historically (Nobriga et al. 2005; Feyrer et al. 2007). There is a
8　significant relationship between turbidity and delta smelt populations in the San Joaquin region of
9　the Delta during the summer months (Nobriga et al. 2008) and in the fall (Feyrer et al. 2011). The
10　reduced turbidity may alter habitat for delta smelt in the central and south Delta and result in
11　reduced use of this area by delta smelt. To successfully feed, larval delta smelt need a high turbidity
12　level; Baskerville-Bridges and coauthors (2004) found that delta smelt were less successful feeding
13　in clear water than in highly turbid water, although turbidity in this study resulted from
14　phytoplankton rather than suspended sediment. It is unknown whether turbidity is important for
15　longfin smelt feeding. Low turbidity also is associated with increased predation by nonnative fish on
16　native fish, including covered species.

5.F.4.2.1.7　　Changes in Nutrient Dynamics and Foodweb Structure

18　Dense patches of IAV may fundamentally change the foodweb in nearshore and shallow-water
19　habitats in several ways. The sedimentation caused by IAV affects phytoplankton and zooplankton
20　abundance by sequestering nutrients, resulting in a decrease in phytoplankton in the water column.
21　In lakes, dense IAV has been shown to serve as a refuge from predators for zooplankton (Stansfield
22　et al. 1997).

23　Dense patches of IAV block light penetration into the water column in nearshore, shallow,
24　freshwater habitat, which can create an undesirable and anoxic habitat for diatoms, phytoplankton,
25　and zooplankton. Consequently, these organisms are less successful in areas occupied by IAV. These
26　organisms are the primary food of copepods, which in turn are the primary food of all life stages of
27　delta smelt and the early life stages of longfin smelt. The presence of *Egeria*-dominated SAV
28　displaces planktonic foodwebs that would occur in warm, well-lit, shallow nearshore habitats.

29　The two extensive IAV species in the Delta, *Egeria* and water hyacinth, have been shown to support
30　invertebrate assemblages living epiphytically on the plants that are different from those supported
31　by native SAV and FAV species. Toft (2000) found differences in the Delta between the invertebrate
32　assemblages on water hyacinth and on a native FAV plant, water pennywort (*Hydrocotyle*
33　*umbellata*)—water hyacinth supported a higher density of a nonnative amphipod not prevalent in
34　fish diets, whereas water pennywort supported a higher density of a native amphipod favored by
35　fish. *Egeria* serves as a substrate for epiphytic algae that are part of the foodweb, and two of the
36　grazing amphipods that live in *Egeria*, *Gammarus daiberi* and *Hyalella azteca*, are important food for
37　native fish (Grimaldo et al. 2009b), but because native fish do not use dense *Egeria* stands, this food
38　source is functionally unavailable. Recently, initial observations have shown that the native sago
39　pondweed supports a high abundance of epifaunal invertebrates (Boyer 2012).

40　Because IAV species support distinct invertebrate assemblages that form the prey base for some
41　covered fish species, removal of dense IAV may change productivity or food availability for covered
42　species. The field evidence suggests that native SAV and FAV species may support a higher
43　proportion of native invertebrates that are favored by, and available to, native fish (Toft 2000). This

1   suggests that a shift from nonnative to native SAV/FAV could change the invertebrate assemblage
2   and therefore affect organisms higher up in the foodweb.

3   IAV may reduce downstream transport of organic material. The presence of IAV, especially SAV, can
4   influence the distance that exported organic material can travel, potentially reducing transport of
5   food resources from the upstream ROAs (e.g., Cache Slough, Yolo Bypass, and South Delta) to areas
6   within the distribution of delta smelt (Kneib et al. 2008).

7   ### 5.F.4.2.1.8   Increased Predation Risk on Covered Species

8   Dense stands of *Egeria*-dominated SAV increase the predation risk on covered species by providing
9   cover for nonnative predatory fish, and enhancing predator foraging efficiency by decreasing
10 turbidity. These relationships are discussed further in Section 5.F.5, *Fish Predation*.

11 ### 5.F.4.2.1.9   Alternative Paths to Control the Spread of
12   Invasive Aquatic Vegetation

13 If the underlying cause(s) of the recent rapid spread of IAV in the Delta were known, one path to
14 controlling the spread could be to address those causes. One alternative hypothesis is that the IAV
15 expansion is a symptom of recent changes in nutrient load (Glibert et al. 2011) and that shifting the
16 nutrient load back to some pre-existing level could control IAV. Alternatively, the symptom—IAV—
17 can be dealt with directly by removing the IAV. The nutrient shift hypotheses (Glibert et al. 2011) is
18 an emerging idea that is not yet well understood, and because it would be very difficult to change
19 quickly, manipulating nutrient levels in the Delta is not a feasible method of controlling IAV in the
20 near term. Furthermore, laboratory results show that, in *Egeria* at least, growth may be limited by
21 inorganic carbon shortage, suggesting that nitrogen and phosphorus may be secondary in
22 controlling growth (Freitas and Thomaz 2011). Therefore, there is more uncertainty in controlling
23 eutrophication (the process of nutrient enrichment which encourages aquatic plant growth and
24 oxygen depletion harmful to covered fish species) as a strategy to reduce IAV compared to removal
25 of IAV using mechanical, chemical, and biological means, which has proven effective in many cases.
26 However, measures to decrease ammonium discharge from wastewater treatment plants are being
27 implemented in response to new regulatory requirements, as discussed in Appendix 5.D,
28 *Contaminants*.

29 ### 5.F.4.2.2   Invasive Aquatic Vegetation Removal Hypotheses and
30   Assumptions

31 The general hypotheses are that *CM13 Invasive Aquatic Vegetation Control* can achieve IAV control at
32 a magnitude sufficient to result in beneficial outcomes on water quality and covered fish species
33 populations and without significant negative effects, in particular, avoiding adverse effects from the
34 use of herbicides.

35 To achieve effective control, the amount of IAV successfully treated must be greater than the spread
36 and growth rate of the plant. To result in positive outcomes for covered fish, the potential negative
37 effects of herbicide use must be minimized, while the potential benefits of increasing turbidity and
38 reducing predation must be realized.

39 Note that eradication or complete removal from the ecosystem of these IAV species established in
40 the Delta is not considered possible. Consequently, CM1's goal is to reduce selected areas of IAV

1   biomass to the level where it no longer causes adverse effects on water quality, aquatic habitats,
2   covered fish, and other native fish and wildlife described above.

3   The approach proposed for CM13 is similar to the overall approach of DBW's existing IAV control
4   programs: treatment of target areas (for DBW, these consisted of sites where *Egeria* interfered with
5   navigation) and nursery sites (i.e., source populations, primarily shallow-water areas that provide
6   ideal habitat for *Egeria*) (California Department of Boating and Waterways 2001). CM13 will build
7   on the knowledge and experience developed over the years by the DBW program, using the methods
8   and herbicide formulations and implemented under the same permit conditions and approvals. The
9   amount of acres proposed for herbicide treatment annually under CM13 is similar to the amounts
10 treated annually, or planned for treatment, under the DBW programs.

5.F.4.2.3   Existing Invasive Aquatic Vegetation Control Programs

12 To evaluate the potential effectiveness of the proposed CM13, it is useful to review the extent and
13 success of the established EDCP and WHCP.

14 The DBW was designated the lead state agency to combat the negative effects of *Egeria* and water
15 hyacinth on navigation in the Delta, its tributaries, and Suisun Marsh. DBW launched the WHCP in
16 1982 and the EDCP in 2001. In August 2012, DBW was authorized as the lead agency to control the
17 recently introduced South American spongeplant, although no control program for this species has
18 yet been implemented.

19 Both programs were the subject of environmental impact reports (EIRs), and addenda where
20 required by program changes, that disclosed and analyzed potential adverse effects of the proposed
21 herbicide treatments on aquatic organisms, including covered fish and water quality. The primary
22 treatment method for both programs is herbicide application, using four common herbicides—
23 Weedar 64® (2,4-D), Rodeo® (glyphosate), Sonar® (fluridone), and Reward® (diquat), and the
24 adjuvants Agri-Dex® and R-11®. In addition, experiments were conducted with the copper-
25 containing herbicide Komeen, but it was not used in the control programs.

26 Table 5.F.5-1 lists the environmental documents with a brief description of the proposed
27 treatments, including proposed treatment acreages.

1 **Table 5.F.5-1. Environmental Impact Reports Prepared for the *Egeria Densa* and Water Hyacinth**
2 **Control Programs**

Environmental Document	Proposed Treatment	Proposed Acreage
Egeria Densa Control Program		
2001 *Egeria Densa* EIR	Use of fluridone and diquat to control *Egeria* where it interferes with navigation and also nursery areas.	Up to 1,538 acres for years 1 and 2; 1,733 acres for years 3 to 5 at 35 priority sites.
2003 Addendum to 2001 EIR	Addition of a new fluridone formulation, Sonar PR® use	No change in acreage.
2006 Second Addendum to 2001 EIR with Five-Year Program Review and Future Operations Plan	Franks Tract Management Area; addition of new fluridone formulation, Sonar Q® use; early-season treatment beginning April 1.	Plans to treat between 3,000 and 5,000 water acres in total per year, of which Franks Tract is approximately 3,000 acres; expand sites to 73.
Water Hyacinth Control Program		
2009 Draft PEIR	Use of 2,4-D (and minor use of glyphosate) in a program is based on Integrated Pest Management and Maintenance Control Practices.	Up to 2,770 acres (the most treated in one year (2004), but in reality much less because the overall extent has been much reduced since then.

3

4 ### 5.F.4.2.3.1   Permitting

5 The herbicides are registered and labeled for aquatic use by the U.S. Environmental Protection
6 Agency (EPA) and by the California Department of Pesticide Regulations for use in California.
7 Registration of an herbicide involves many years of research and is considered the functional
8 equivalent of an EIR for the purposes of the California Environmental Quality Act (CEQA).

9 To comply with other federal and state regulations, the EDCP and WHCP required the following
10 permits:

11 ● Two biological opinions (BiOps) were required under the ESA[2].

12   ○ A USFWS BiOp was required for Sacramento splittail, giant garter snake, valley elderberry
13   longhorn beetle, and delta smelt.

14   ○ An NMFS BiOp was required for winter-run Chinook salmon, spring-run Chinook salmon,
15   steelhead, and green sturgeon.

16 ● The Central Valley Regional Water Quality Control Board (Central Valley Water Board) required
17   an National Pollutant Discharge Elimination System (NPDES) permit.

18 The BiOps identified possible direct and indirect adverse effects that the WHCP and EDCP might
19 have on federally-listed species and specified requirements for avoidance and minimization of
20 effects on listed species.

21 NPDES permits are required for all aquatic pesticide applications in California. The NPDES permit
22 goals were to minimize the extent of potential impacts on water quality in the Delta and to create a

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[2] The federal nexus for this activity is the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS), which is responsible for conducting research and providing technical input into the control of nuisance weeds and agricultural pests.

1 water monitoring and reporting program. The Central Valley Water Board imposed the following
2 monitoring protocols on the EDCP and WHCP:

3 ● Document compliance with the permit requirements.

4 ● Support the development, implementation, and effectiveness of best management practices
5   (BMPs).

6 ● Demonstrate the full recovery of water quality and protection of beneficial uses of the receiving
7   waters after treatment applications.

8 ● Monitor all pesticides and application methods used.

9   The permits obtained for the EDCP for the initial 5 years (2001 to 2005) proposed treatment
10 acreages of 1,531 acres in 2001 and 2002 and 1,631 acres in 2003, 2004, and 2005—a total of
11 8,105 acres (Table 5.F.5-2).

12 **Table 5.F.5-2. List of Permits Required for the *Egeria Densa* Control Program (2001–2005)**

Agency	Permit Type	Permit
U.S. Fish and Wildlife Service	Biological opinion	● 2001–2003 1-1-00-F-0234, as amended ● 2004–2005 1-1-04-F-0148
National Marine Fisheries Service	Biological opinion	● 2001 SWR-99-SA-0053 letter ● 2002 SWR-99-SA-104 ● 2003–2005 SWR-02-SA-8279, as amended
Central Valley Regional Water Quality Control Board	National Pollutant Discharge Elimination System Permits	● 2001–2002 CA0084735 (Individual) ● 2002–2003 CA990003 (General) ● 2004–2005 CA990005 (General)

13

14 These permits placed restrictions on where and when herbicide treatment could occur, established
15 the allowable chemical concentrations in treated areas and adjacent waters, and required extensive
16 water quality monitoring and toxicity research. In addition to the conditions and restrictions in the
17 above permits, the EIRs and addenda for the EDCP (California Department of Boating and
18 Waterways 2001, 2006) and the programmatic EIR for the WHCP (California Department of Boating
19 and Waterways 2009) contain avoidance and mitigation measures designed to reduce adverse
20 effects on sensitive species, natural communities, and water quality.

21 The herbicide programs are obliged to follow the California Department of Pesticide Regulation
22 procedures for pesticide application and to comply with all requirements of the Division 6 Pesticides
23 and Pest Control Operations of the federal Food and Agriculture Code covering labeling, handling,
24 transportation, mixing, and rinsing containers. Additional requirements include a memorandum of
25 understanding between DBW and regional water agencies outlining application restrictions relating
26 to drinking water intakes and filing a Notice of Intent with the County Agricultural Commissioner of
27 each county where herbicide use occurs.

28 The herbicides and application protocols currently used in the DBW program have evolved in an
29 adaptive management context over many years of research, efficacy monitoring, water quality
30 monitoring, and toxicity testing to balance effective removal of IAV while minimizing the risk to
31 other aquatic organisms, including covered fish.

1   ### 5.F.4.2.3.2   Control of Brazilian Waterweed (*Egeria densa*)

2   *Egeria* continues to be the most extensive and problematic IAV in the Delta, absorbing the majority
3   of resources for control efforts. Since 2001, DBW has been treating *Egeria* on a medium to large
4   scale (hundreds to thousands of acres per year), with successful outcomes.

5   Initially (2001 and 2006), DBW treated 268 to 622 acres per year. These amounts were lower than
6   planned and permitted—only 1/3 of the total allowed treatment acres—because of resource
7   limitations. In addition, seasonal permit restrictions meant that herbicide treatment could not be
8   started early in the season when control would be most effective (California Department of Boating
9   and Waterways 2006).

10   In 2006, DBW concluded that its program of herbicide treatment can be effective on a site-specific
11   level. However, it was not capable of eradicating *Egeria* in the Delta or even keeping up with the
12   overall rate of spread (California Department of Boating and Waterways 2006). Because of resource
13   limitations, the program could not treat enough sites across the Delta, or treat a large enough
14   proportion of those treated sites, or treat sites intensively enough to achieve overall control. Most
15   importantly, because of permit conditions, DBW was not able to treat *Egeria* early in the year when
16   treatment was known to be much more effective.

17   Two important changes occurred in 2006: toxicity monitoring was no longer required as a permit
18   condition, saving $1 million/year in environmental monitoring costs; and early application in April
19   was permitted, allowing much more effective control. Beginning in 2007, DBW instituted a
20   3,000-acre, 3-year, Franks Tract area management focus, initially treating 1,400 acres in 2007 and
21   an additional 1,100 acres in 2008. The net result was a reduction in 1,500 acres of cover of *Egeria* in
22   Franks Tract, a 47% reduction in area (Ustin 2008; Santos et al. 2009), and significant reduction in
23   biovolume (Ruch and California Department of Boating and Waterways, Aquatic Weed Unit 2006).
24   The additional treatment in 2008 yielded a further 50% reduction (Santos et al. 2009). Similar
25   results were achieved at Fourteenmile Slough, a smaller site (Santos et al. 2009).

26   Cover of *Egeria*-dominated SAV was measured from aerial imagery from 2004 to 2007 (Ustin 2008)
27   (Table 5.F.5-3). Delta-wide, there was a relatively small loss of 356 acres between 2006 and 2007 (a
28   0.34% reduction) because the large site-specific losses at Franks Tract and Big Break were offset by
29   continued spread throughout the rest of the Delta. These figures demonstrate the reduction
30   achieved at Franks Tract, while showing that *Egeria* continued to increase approximately 1,500
31   acres per year, or about 15%; this is in line with earlier DBW estimates of 10 to 12% increase per
32   year (California Department of Boating and Waterways 2006).

1   **Table 5.F.5-3. Acres of Submerged Aquatic Vegetation in Delta by Subregion**

Subregion	Waterways Area (Acres)	Acres of Submerged Aquatic Vegetation (%)			
		June 2004	June 2005	June 2006	June 2007
Cache Slough	7,081	209 (3%)	466 (7%)	213 (3%)	349 (5%)
East Delta	5,182	695 (13%)	1,363 (26%)	1,018 (20%)	2,129 (41%)
North Delta	4,693	329 (7%)	596 (13%)	461 (10%)	357 (8%)
South Delta	19,608	3,068 (16%)	3,834 (20%)	3,791 (19%)	3,747 (19%)
West Delta	16,771	2,574 (15%)	3,937 (23%)	4,720 (28%)	3,276 (20%)
Yolo Bypass	1,517	122 (8%)	176 (12%)	175 (12%)	162 (11%)
All Delta	**54,852**	**6,997 (13%)**	**10,372 (19%)**	**10,378 (19%)**	**10,020 (18%)**
Source: Ustin 2008.					

2

3   Based on these figures, therefore, annual treatment of around 1,500 acres could maintain the
4   current status-quo Delta-wide, and a greater acreage could start to incrementally reduce the overall
5   extent of *Egeria*. The success of the Franks Tract herbicide treatments in 2007 and 2008 has
6   demonstrated that treating this number of acres is feasible and can be successful in reducing the
7   amount of *Egeria* (Santos et al. 2011). CM13 proposes to treat between 1,700 acres per year (low
8   estimate) and 3,400 acres per year (high estimate), which based on the total cover estimate of
9   approximately 10,000 acres (Ustin 2008), would represent a 17% to 34% annual reduction Delta-
10   wide. Compounded over the life of the Plan, this could result in a significant reduction in *Egeria*
11   extent in the Delta. Projected changes in the total acreage of *Egeria* under the low and high
12   treatment estimates at two assumed rates of *Egeria* expansion, 10% and 20%, with a worst-case
13   starting point of 14,000 acres (estimated in 2006 [California Department of Boating and Waterways
14   2006]) are shown in Figure 5.F.5-3.
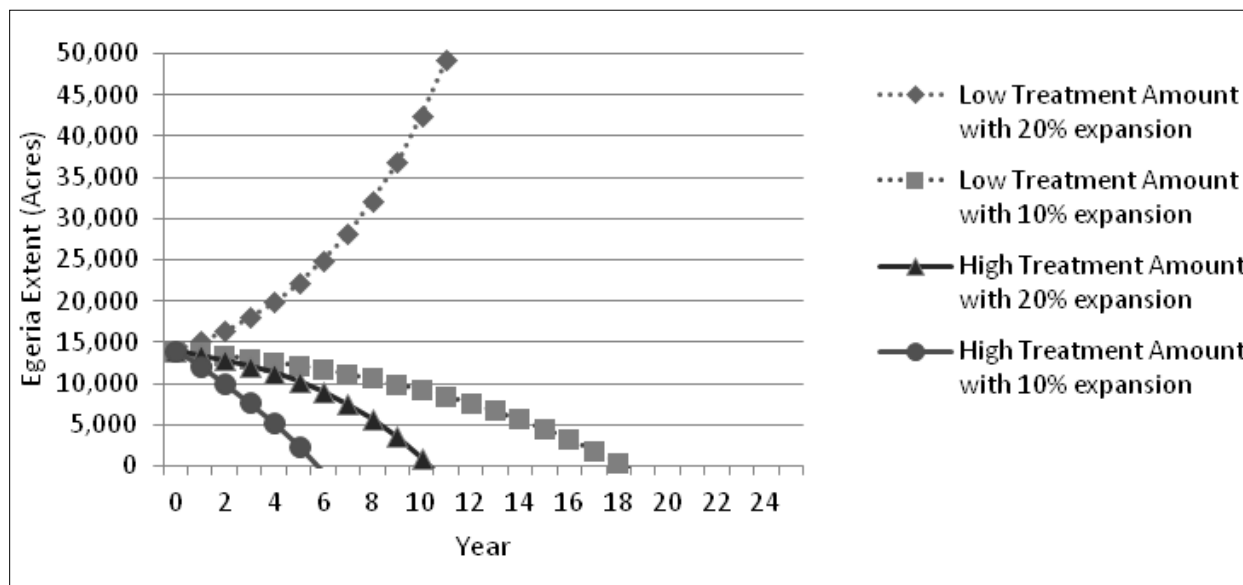
15
16   **Figure 5.F.5-3. Projected Changes in Delta-wide Extent of *Egeria* under Low and High Treatment**
17   **Amounts and Two Different Projected Rates of *Egeria* Increase**

1   The projection shows that applying the high treatment estimate while *Egeria* expands at 10% per
2   year could result in effective control within 6 years. Applying the low treatment amount with 10%
3   expansion could lead to control within 20 years. However, the low treatment estimate would not
4   result in effective control if *Egeria* were to expand at 20% per year. While clearly a simplification,
5   this projection provides some reassurance that reduction of *Egeria* Delta-wide is possible under the
6   proposed CM13 and within the time period of the Plan.

7   One major assumption is that effective control could be achieved with a single treatment. In fact,
8   additional treatment may be required if *Egeria* coverage were not significantly reduced by one
9   treatment or the treated area was recolonized. Techniques to improve effectiveness already
10   implemented by the DBW program include treating entire areas early in the year when treatment is
11   most effective, with follow-up monitoring to detect and spot treat grow-back in the late
12   summer/fall.

13   Another assumption is that all aquatic habitat in the Delta (54,000 acres of waterways) provides
14   suitable habitat for *Egeria*. In fact, the spread of *Egeria* in the Delta is limited by salinity, water
15   depth, and flow velocity. Indeed, there have been recent signs that the rate of spread of *Egeria* may
16   be slowing, perhaps because it is coming close to occupying most of the suitable habitat (Hestir pers.
17   comm. cited in Baxter et al. 2010). However, the shallow freshwater areas created by habitat
18   restoration under the Plan (discussed below) have the potential to create additional suitable habitat
19   for IAV, and *Egeria* in particular and could thereby facilitate the spread of *Egeria*.

20   The DBW program demonstrated early on that local and medium-scale site-specific treatment was
21   successful in controlling *Egeria* while avoiding or minimizing adverse effects on covered fish species.
22   Based on this, it is expected that localized or spot-treatment of early infestations in newly restored
23   areas would be effective in controlling *Egeria* within ROAs and would not have adverse effects on
24   covered fish. In addition, the more recent large-scale success at Franks Tract has demonstrated that
25   large-scale treatment of *Egeria* early in the growing season also can be successful while avoiding or
26   minimizing adverse effects on covered fish. It is therefore expected that large-scale treatment of
27   source areas proposed under CM13 would achieve similar levels of success in controlling *Egeria*
28   while avoiding adverse effects on covered fish.

5.F.4.2.3.3   Control of Water Hyacinth

30   Water hyacinth is the second species targeted by DBW. In 1981, it covered 1,000 acres of the Delta
31   (U.S. Army Corps of Engineers 1985). Water hyacinth mats can double in size in 6 to 15 days during
32   the warm summer months (Harley et al. 1996). The DBW control program began in 1983.

33   Between 1988 and 2008, the WHCP treated a total of 10,360 acres (Santos et al. 2009), an average of
34   518 acres per year. Between 2001 and 2007, over 1,000 acres were treated each year, with more
35   than 2,000 acres treated each year from 2002 to 2006 (California Department of Boating and
36   Waterways 2009). At its greatest extent, water hyacinth was estimated to cover 2,500 acres. Overall,
37   water hyacinth cover declined between 2003 and 2006 (Santos et al. 2009). In 2006, water hyacinth
38   was estimated to cover 700 acres, almost double the area in 2005; in 2007 cover was 139 acres; in
39   2008, the extent of water hyacinth was below the level that could be estimated (Ustin 2008). The
40   evidence suggests that the DBW program has reduced water hyacinth cover, and therefore the
41   program can be considered successful in controlling water hyacinth across the Delta (Santos et al.
42   2009; Baxter et al. 2010).

1   ## 5.F.4.2.4   Invasion Potential of *Egeria* in Restoration Opportunity Areas

2   Restoration of aquatic habitats proposed under CM4 will create additional suitable freshwater
3   habitat for *Egeria*. Laboratory experiments and field observations both demonstrate that *Egeria* is
4   an effective colonizer capable of very high growth and expansion. Laboratory experiments
5   demonstrated that growth rates were highest when the density of *Egeria* was low at the beginning
6   and declined as the experiment progressed because of the increase in biomass and density, rather
7   than depletion of nutrients or reduction in light penetration (Pistori et al. 2004). This may translate,
8   in the favorable temperature conditions in the Delta, to a rapid regrowth of *Egeria* after an
9   immediate post-treatment decline, especially because *Egeria* has a bi-modal growth pattern in the
10   Delta, with a second peak in growth in late fall (Pennington and Sytsma 2009). DBW found that
11   grow-back can be significant after treatment; for example a 55% increase was recorded within
12   1 year at nine sites (California Department of Boating and Waterways 2006).

13   *Egeria* has invaded newly occurring wetlands in the Delta: in a study of three breached levee
14   wetlands, *Egeria* and Eurasian water milfoil were found to be the dominant SAV species that
15   colonized the shallow (<4 meters deep) subtidal areas (Grimaldo et al. 2009). Measures such as
16   manipulation of water velocity (Section 5.F.4.2.4.3) could be incorporated into the design of
17   restoration sites to reduce the risk of *Egeria* colonization colonizing restoration sites.

18   Results are discussed below for analyses of the amount of area within the ROA footprint area that
19   would provide suitable conditions of water depth, salinity, water velocity, and turbidity for *Egeria*
20   within the ROA footprint area. The analyses, combined with ongoing research in the Delta, also
21   suggests ways natural community restoration sites could be designed to minimize the risk of IAV
22   establishment and spread.

23   ### 5.F.4.2.4.1   Water Depth

24   *Egeria* typically roots in a water depth of up to approximately 3 meters in the Delta (California
25   Department of Boating and Waterways 2001). Restoration of aquatic habitats in the ROAs will
26   create a total of 55,000 acres over the life of the Plan. A habitat suitability analysis based on earlier
27   BDCP projections of 74,000 acres of aquatic habitat restoration over the life of the Plan found that
28   45,000 acres (61%) would be projected to be less than 3 meters below mean tide level (MTL),
29   providing suitable habitat for *Egeria* (Table 5.F.5-4). The analysis was repeated using a maximum
30   depth of 4 meters below MTL instead of 3 meters. Small increases in the amount of habitat would
31   occur (less than 3% of the project area for all ROAs), indicating the *Egeria* habitat area is not
32   particularly sensitive to this parameter in all ROAs.

33   **Table 5.F.5-4. Acres of Suitable *Egeria* Habitat within ROAs Based on Water Depth**

Restoration Opportunity Area	Total Project Area Footprint (Acres)	Depth < 3 meters		Depth < 4 meters	
		Egeria Habitat (Acres)	Percent of Project Area	*Egeria* Habitat (Acres)	Percent of Project Area
Suisun Marsh	15,620	11,225	71.9%	11,302	72.4%
Cache Slough	26,411	11,033	41.8%	11,769	44.6%
West Delta	4,238	3,599	84.9%	3,720	87.8%
Cosumnes-Mokelumne	5,018	3,007	59.9%	3,014	60.1%
South Delta	22,483	15,801	70.3%	15,899	70.1%
Total	**73,770**	**44,665**	**60.5%**	**45,704**	**62.0%**

34

1   ### 5.F.4.2.4.2   Salinity

2   Salinities above 8 to 10 ppt greatly slow or prevent growth of *Egeria* (Hauenstein and Ramirez 1986;
3   Obrebski and Booth 2003). However, these high salinity values are rarely reached in most of the
4   Delta, even during low flow periods. For example, during the low flow and peak salinity intrusion of
5   fall 2002, the 1 ppt extended only into approximately half of the West Delta ROA. This salinity value
6   is too low to have an inhibiting effect on *Egeria* growth. However, in the Suisun ROA, most of the
7   *Egeria* habitat is subjected to peak salinities above 10 ppt, and this value persists throughout the
8   western portion of the ROA during much of the 3-month low flow period in the fall, and would limit
9   or even prevent the establishment of *Egeria* in these areas. In the eastern and southern portions of
10   the Suisun ROA, salinities above 8 ppt are persistent through the fall, a value that is expected to
11   severely retard the growth and spread of *Egeria* through these months.

12   ### 5.F.4.2.4.3   Water Velocity

13   Flow velocities can limit *Egeria* establishment. Hestir and coauthors (2010a) tested for a maximum
14   annual channel water velocity critical to *Egeria*-dominated SAV cover in the Delta using flow data for
15   3 years. The study found that channels where the annual maximum channel velocity exceeded 0.49
16   m/sec (1.61 fps) had significantly lower cover than sites with a lower velocity. Noting that other
17   studies had found similar flow thresholds controlling SAV, Hestir concluded that a single flow event
18   over 1.61 fps limits *Egeria* presence in the Delta. Note that *Egeria* is not eliminated above this
19   threshold, but the cover is significantly lower (typically less than 5%, with an average of less than
20   2%) (Hestir et al. 2010a).

21   The potential for the ESO and habitat restoration to affect *Egeria* distribution within the Plan Area
22   was examined by evaluating maximum annual channel velocity at 66 locations (1976–1991 water
23   years simulated with DSM2). For each channel location in the DSM2 output, the maximum annual
24   velocity in each year was categorized as being above or below the 1.61-fps *Egeria*-limiting threshold
25   velocity. Some channels in tidal areas have appreciable bidirectional flows and so the absolute
26   values of the minimum (negative) flows are also taken into account. The number of years (out of the
27   16 years available in the simulation) a given channel had a maximum or minimum velocity below
28   the *Egeria*-limiting threshold were counted and compared (ESO scenarios to baseline conditions).
29   For each channel, the number of years below the *Egeria*-limiting threshold velocity was compared
30   for EBC2_ELT vs. ESO_ELT and EBC2_LLT vs. ESO_LLT scenarios; these scenarios were chosen to
31   account for potential climate change-related differences and also to limit the output for the large
32   number of available locations. Locations in the Suisun Marsh and Suisun Bay subregions were not
33   considered because salinity is too high for *Egeria*.

34   There were few locations that had appreciable differences in the number of years below the 1.61-fps
35   *Egeria* threshold velocity between EBC2_ELT/EBC2_LLT and ESO_ELT/ESO_LLT. Averaged across all
36   of the modeled locations in all subregions, there were 6% more years below the *Egeria* threshold
37   under ESO_ELT vs. EBC2_ELT; the result was similar (7%) for ESO_LLT vs. EBC2_LLT. Out of the 66
38   locations in the analysis, differences between scenarios in the number of years with maximum flows
39   below the 1.61-fps *Egeria*-limiting velocity occurred at only 20 locations (Table 5.F.5-5).

Table 5.F.5-5. Locations and Frequency of Channel Velocities Exceeding *Egeria*-Limiting Threshold of 1.61 Feet Per Second

Location	Number of Years below 1.61 fps *Egeria*-Limiting Threshold[1]							
	Minimum Velocity[2]		Maximum Velocity		Minimum Velocity[2]		Maximum Velocity	
	EBC2_ELT	ESO_ELT	EBC2_ELT	ESO_ELT	EBC2_LLT	ESO_LLT	EBC2_LLT	ESO_LLT
Sacramento River upstream Sutter and Steamboat (downstream of north Delta diversion)	ND	ND	ND	ND	ND	ND	0	1
Sutter Slough at Head	ND	ND	ND	ND	ND	ND	0	1
Steamboat Slough downstream of Sutter Confluence	ND	ND	ND	ND	ND	ND	0	1
Sacramento River downstream of Sutter Slough	ND	ND	ND	ND	ND	ND	0	1
Sacramento River downstream of Steamboat Slough	ND	ND	ND	ND	ND	ND	0	1
Sacramento River upstream of DCC	ND	ND	0	1	ND	ND	0	1
Delta Cross Channel	ND	ND	7	16	ND	ND	5	15
Sacramento River downstream of Georgiana Slough	ND	ND	ND	ND	ND	ND	0	1
Georgiana Slough	ND	ND	ND	ND	ND	ND	0	1
Threemile Slough	0	16	0	16	0	16	0	16
South Fork Mokelumne River at Staten Island (Terminous)	ND	ND	15	16	ND	ND	ND	ND
Montezuma Slough at Beldon's Landing	15	16	3	16	13	16	1	15
San Joaquin River at San Andreas Landing	ND	ND	2	6	ND	ND	0	4
San Joaquin River at San Andreas	ND	ND	0	11	0	1	0	12
False River at Russo Landing	ND	ND	3	11	10	16	0	14
San Joaquin River at Brandt Bridge	ND	ND	5	6	ND	ND	4	8
Old River at Head	ND	ND	8	9	ND	ND	ND	ND
Grant Line Canal	ND	ND	8	9	ND	ND	8	10
Old River at Clifton Court	ND	ND	ND	ND	ND	ND	0	5
San Joaquin River at Dos Reis	ND	ND	ND	ND	ND	ND	4	8

[1] ND = No difference between scenarios in the number of years during which the annual velocity was below the *Egeria*-limiting threshold.

[2] Minimum Velocity indicates number of years during which lowest flow is below threshold and is included to account for sites with appreciable negative (reverse) flows.

The results generally were consistent between the ELT and LLT time periods but differed by subregion. There was little to no difference between EBC2 and ESO scenarios at locations in the Cache Slough, North Delta, and South Delta subregions. In the East Delta subregion, the ESO_ELT and ESO_LLT scenarios had an average of around 10 out of 16 years below the *Egeria* threshold velocity, compared to around 7 out of 16 years for the EBC2_ELT and EBC2_LLT scenarios. This was largely due to changes in the Delta Cross Channel annual velocity maxima.

1   The West Delta subregion had the largest average difference between EBC2 and ESO scenarios in the
2   number of years below the critical 1.61-fps *Egeria* threshold velocity, which was 19 to 23% greater
3   under the ESO_ELT and ESO_LLT scenarios. The results were driven by large differences at the
4   Threemile Slough, False River at Russo Landing, and San Joaquin River at San Andreas locations,
5   where maximum annual velocity was above the *Egeria* threshold under EBC2 in all or nearly all
6   years, and below the threshold in all or nearly all years under ESO scenarios. There was little to no
7   difference in the number of years below the critical 1.61-fps *Egeria* threshold velocity for the
8   remaining locations in the West Delta subregion. The results for the West Delta subregion can be
9   attributed in large part to assumptions regarding restoration in the West Delta ROA, which lead to
10   substantial muting of tidal velocities at nearby locations, in particular at Threemile Slough.

11   Overall, the analysis of *Egeria* habitat suitability in relation to a maximum annual channel velocity
12   criterion suggested a small difference between EBC2 and ESO scenarios, with a greater number of
13   years below the threshold being mostly found at locations close to the West Delta ROA. In most
14   subregions (Cache Slough, North Delta, and South Delta), annual maximum velocities would not
15   change much as a result of BDCP implementation, suggesting that the potential for *Egeria* presence
16   at these locations would not change. In the East Delta, maximum flow velocities would decrease in
17   the Delta Cross Channel with BDCP implementation, and there would be more years during which
18   flows would not reach the *Egeria*-limiting threshold, thus increasing the potential for *Egeria* to
19   colonize.

20   Results of the comparison of scenarios at West Delta locations suggest that habitat restoration under
21   the BDCP would cause tidal muting that would reduce annual maximum velocity, which could
22   increase the potential for *Egeria* to colonize these locations because flows are reduced to below the
23   limiting threshold.

24   Other factors such as water depth and turbidity are also important in determining *Egeria* habitat
25   suitability, however, the velocity-based analysis provides a first-order indication of potential
26   differences under the ESO.

5.F.4.2.4.4   Turbidity

28   High turbidity limits light penetration in the water column and may inhibit the establishment and
29   growth of *Egeria*. High turbidity values in Cache Slough and Liberty Island might possibly limit the
30   extent of potential egeria habitat in the Cache Slough ROA. However, this is hard to assess from a
31   quantitative perspective based on the feedback loops that occur between *Egeria* establishment and
32   growth, water velocities, and turbidity from resuspended sediment. An additional factor that affects
33   turbidity is wind, through a "fetch effect": a longer fetch, or distance is associated with stronger
34   winds, leading to larger wind waves and increased sediment resuspension (May et al. 2003). It
35   might be possible to design restoration site geometry in ROAs to harness this effect with the aim of
36   increasing turbidity, thereby reducing the potential for *Egeria* to establish or spread.

5.F.4.3 Potential Effects: Benefits and Risks

5.F.4.3.1 CM13 Invasive Aquatic Vegetation Control

5.F.4.3.1.1 Potential Beneficial Outcomes

Increased Food Consumption by Delta and Longfin Smelt due to Higher Turbidity

Control of IAV, particularly *Egeria*-dominated SAV, aims to improve conditions for delta and longfin smelt by removing the invasive aquatic vegetation associated with a decrease in turbidity. The delta smelt model (Nobriga and Herbold 2008) indicates the ability of delta smelt larvae and juveniles to see prey is enhanced by suspended particles, although it is uncertain whether this depends on concentration of suspended sediment or suspended algae. The implications for longfin smelt are unclear. Analysis of historical turbidity data and estimates of SAV cover from 1975 to 2008 showed a Delta-wide relationship between increasing SAV cover and decreasing turbidity (Hestir et al. 2010b).

Removal of SAV likely could improve conditions for delta and longfin smelt by removing the aquatic vegetation associated with a decrease in turbidity. Reduced IAV could promote increased turbidity and therefore would improve habitat conditions for delta smelt and by improving the ability for larval smelt to feed. Longfin smelt would not be as strongly affected by this action because they occur infrequently in the central and south Delta and only during the drier years, and the time they would be in this part of the Delta would be relatively shorter and would occur when turbidity is controlled more by storm flows than by IAV. Currently, the high turbidity in the winter/spring that cues upmigration in delta smelt results from high winter inflows. Results from one relatively large treatment to control *Egeria*-dominated SAV at Franks Tract showed a small short-term and localized increase in turbidity, but still below the levels critical to delta smelt (Hestir et al. 2010a). Continuous turbidity measurements showed several severe turbidity events during the winter following successful SAV reduction at Franks Tract, again suggesting that SAV removal could, at least in the short term, produce an increase in turbidity by increasing sediment suspension. It is not yet known whether larger scale IAV removal will bring larger scale and longer-term increases in turbidity. Turbidity is discussed in greater detail in Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*.

Removal of IAV also may benefit smelt by allowing nearshore foodwebs to reestablish, which may increase local planktonic food supplies for delta and longfin smelt. In the absence of IAV, primary production would shift to phytoplankton and the foodweb it supports—see Appendix 5.E, *Habitat Restoration,* for discussion of foodweb changes.

Based on current data, the removal of IAV could have a minor beneficial impact on delta and longfin smelt. However, it is uncertain whether IAV removal at the scale planned under the BDCP would result in increased turbidity beyond a localized scale and at a sufficient magnitude to increase food consumption in delta and longfin smelt.

Reduced Predation of Delta Smelt as a Result of Increased Turbidity

One hypothesized benefit of IAV removal is that turbidity would increase sufficiently to provide delta smelt a visual refuge from predators. The DBW's *Egeria* removal program in Franks Tract resulted in modest local increase in turbidity (5.1 NTU [2006] increased to 8.3 NTU [2007]) (Hestir et al. 2010a). It is uncertain whether IAV removal would result in increased turbidity beyond a localized scale and at a sufficient magnitude to reduce predation in delta and longfin smelt.

1 **Reduce Predation on Juvenile Salmon, Steelhead, and Splittail by Reducing Habitat for Nonnative**
2 **Predatory Fish**

3 The potential effects of IAV control on reducing predator habitat and therefore predation on covered
4 fish species are discussed in Section 5.F.5, *Fish Predation*.

5 **Increase Rearing Habitat for Juvenile Salmon (All Races), Steelhead, and Splittail**

6 Currently the dense stands of *Egeria*-dominated SAV are believed to block access to suitable rearing
7 areas for juvenile salmonids and splittail (California Department of Boating and Waterways 2006;
8 National Marine Fisheries Service 2007; Interagency Ecological Program 2008). Dense SAV is
9 present in areas that are located along the migration routes of salmonids and that would be treated
10 under the proposed conservation measure, such as channel margin habitat and restored areas.
11 Removal of IAV would restore suitable habitat conditions for juvenile salmonids by restoring access
12 to suitable shallow water habitat. A similar effect would be expected on splittail, but because they
13 rear over a larger area and the treated *Egeria*-dominated SAV areas would be a smaller portion of
14 splittail habitat, the effect would not be as strong. The removal of SAV at restoration sites would be
15 highly likely to provide a moderate beneficial impact for salmonids and a minor to moderate
16 beneficial impact for splittail by maintaining access to and function of shallow water rearing habitat.

17 **Reduced Encroachment of Submerged Aquatic Vegetation into Delta Smelt and Longfin Smelt**
18 **Spawning and Rearing Habitat**

19 Removal of IAV, especially *Egeria*-dominated SAV from areas of the central and north Delta known
20 seasonally to contain delta smelt larvae, may increase habitat use for spawning. Spawning is thought
21 to occur on or over sandy substrates at subtidal elevations, and these are the areas where dense SAV
22 is found. Although little is known of the spawning areas, the extent of overlap between shallow
23 sandy areas suitable for spawning and current dense SAV stands or areas suitable for invasion by
24 SAV has not yet been quantified. Longfin smelt are believed to spawn and rear in areas of the Delta
25 west of the areas currently or potentially affected by SAV, so benefits to longfin smelt spawning and
26 rearing habitat are unlikely.

27 Removal of SAV may increase the amount of habitat potentially available for delta and longfin smelt
28 in nearshore habitats of the Delta. SAV stands physically occupy nearshore habitat that may be used
29 by larval and juvenile smelt. Depending on how delta smelt use marsh edge and shallow-water
30 habitat, the SAV removal may or may not have a substantial effect on larval and juvenile habitat use.
31 If larval and juvenile delta smelt do use this type of habitat and this action successfully prevents SAV
32 from spreading or occupying habitat restoration sites and making them unsuitable for delta smelt,
33 this benefit may be substantial, given the amount of shallow tidal habitat that would be created by
34 the Plan. A similar effect would be expected on longfin smelt, but because of the difference in
35 distribution and timing, the effect would not be as strong.

36 ## 5.F.4.3.1.2 Potential Risks and/or Detrimental Effects

37 **Potential Adverse Effects from Herbicide Toxicity Applied under Permitted Conditions**

38 Under CM13, herbicide treatments would be the primary method to control IAV, because this
39 approach provides rapid and effective control at the scale of the BDCP restoration areas and
40 adjacent areas required to effectively control IAV, and has been used in the Delta since 1983.

1   To meet the requirements of CEQA, the NMFS and USFWS BiOps, and NPDES permit, DBW was
2   required to review and summarize the results of toxicology studies on phytoplankton and
3   zooplankton for each herbicide proposed for use in the program. In addition, DBW undertook and
4   funded research on potential toxic effects of herbicide treatment on nontarget organisms, including
5   aquatic invertebrates and listed fish species. All herbicides registered for aquatic use by the EPA are
6   required to undergo extensive risk assessment and toxicology testing to determine the potential for
7   adverse effects on nontarget organisms and label restrictions. Typically, aquatic herbicides remain
8   conditionally registered, meaning they undergo periodic review under the EPA's Registration
9   Review program; 2,4-D, glyphosate, and diquat have undergone several reviews, while fluridone, a
10 newer herbicide, is entering the first re-review.

11 All herbicides and adjuvants used by the DBW programs are registered and labeled for aquatic use
12 by the EPA and the California Department of Pesticide Regulation. Additional use restrictions,
13 testing, and monitoring were required by the various permitting agencies. To meet the requirements
14 of CEQA, the NMFS and USFWS BiOps, and NPDES permit, DBW was required to review and
15 summarize the results of toxicology studies on aquatic organisms for each herbicide proposed for
16 use in the program. In addition, DBW undertook and funded additional toxicity testing on nontarget
17 organisms, including aquatic invertebrates and listed fish species. Results of the toxicity reviews and
18 additional testing were reviewed by NMFS and USFWS before issuing BiOps that requested
19 avoidance and minimization measures. Details of the toxicity testing are discussed in Appendix 5.D,
20 *Contaminants*.

21 Independent review of aquatic herbicide use by the DBW programs was undertaken by the
22 nonprofit San Francisco Estuary Institute at the request of the State Water Resources Control Board.
23 The institute conducted an EPA Tier 1 risk assessment using standard methods (U.S. Environmental
24 Protection Agency 1998) to determine the potential for adverse effects on the Delta's aquatic
25 ecosystem from DBW's aquatic herbicide use (Siemering 2006). The study compared measured
26 herbicide residues from water samples collected over 3 years (2003, 2004, and 2005) with toxicity
27 values for a range of aquatic species obtained from peer-reviewed academic literature, EPA
28 registration documents, and other government reports to determine risk quotients that were
29 compared with the EPA's Level of Concern (LOC) values for each herbicide:

30 ● 2,4-D—no LOC exceedances out of approximately 1,800 calculations for Risk Quotients.

31 ● Diquat—LOC exceedances were observed in 6% to 19% of Risk Quotients, including some for
32   delta smelt.

33 ● Glyphosate—4 exceedances (1%) in 1 year only.

34 ● Fluridone—LOC exceedances were observed in 4% to 6% of Risk Quotients, all for the aquatic
35   macro algae stonewort; no exceedances were observed for other organisms.

36 Conclusions on the risks of DBW's use of each herbicide were made based on the extent or pattern of
37 observed LOC exceedances (Siemering 2006). The number of exceedances for diquat was not
38 unexpected, as this herbicide was known to have a small margin of safety for covered fish (Riley and
39 Finlayson 2004). To avoid adverse effects on covered fish, diquat is not used when smelt are
40 present, and use in salmonid migration routes is avoided when salmonids are known to be present.
41 As a result of this and other studies, DBW significantly reduced its use of diquat (California
42 Department of Boating and Waterways 2006). Based on the low number of exceedances and the use
43 of glyphosate for terrestrial application in the Delta, the study concluded that DBW's glyphosate use
44 is not likely to pose a risk to the aquatic environment. 2,4-D and fluridone also were considered

1   unlikely to cause toxic effects on nontarget organisms (Siemering 2006). Two of the herbicides are
2   used in large quantities for terrestrial application near sites in the Delta where aquatic herbicides
3   are used; the contribution from DBW's aquatic use may be relatively small for diquat (Siemering
4   2006) and 2,4-D (Siemering et al. 2008). Similarly, surfactants similar to R-11® are widely used in
5   household, industrial, and agricultural products that enter the Delta, and the contribution from
6   aquatic herbicide use may be relatively small (Siemering et al. 2008).

7   The herbicide formulations and application protocols currently used in the established DBW
8   programs have therefore evolved over many years of research, efficacy monitoring, water quality
9   monitoring, and toxicity testing to balance effective removal of IAV while minimizing the risk to
10 other aquatic organisms, including covered fish.

11 **Potential Adverse Effects of Herbicide Toxicity on Aquatic Life Zooplankton and Phytoplankton**

12 The potential effects of herbicide use for IAV control on zooplankton and phytoplankton are
13 discussed in Appendix 5.D, *Contaminants*.

14 Results from water quality monitoring during and after herbicide treatment in the Delta confirmed
15 that fluridone concentrations were maintained within the nonlethal range for aquatic invertebrates
16 (California Department of Boating and Waterways 2006). Similarly, the levels of 2,4-D and
17 glyphosate used in the WHCP are at least one order of magnitude less than impact levels on
18 zooplankton, and significant adverse effects on zooplankton and phytoplankton are unlikely
19 (California Department of Boating and Waterways 2009). Extensive and independent assessment of
20 herbicide use under the existing DBW program has concluded that the use of herbicides to control
21 IAV in the Delta is unlikely to cause toxic effects on nontarget organisms (Siemering 2006). Should
22 toxic effects occur, zooplankton and phytoplankton would readily recolonize the affected area on
23 water currents from adjacent untreated areas.

24 The aquatic herbicides concentrations used by the existing DBW programs therefore are not likely
25 to decrease zooplankton and phytoplankton. The proposed CM13 would use the protocols and
26 herbicide formulations developed by DBW and would treat a similar amount of acres; therefore
27 effects would be minor, and there would be no adverse effects on aquatic life, including
28 phytoplankton and zooplankton.

29 **Potential Toxic Effects of Herbicide on Covered Fish**

30 ***Delta Smelt and Longfin Smelt***

31 The potential effects of herbicide use for IAV control on delta smelt and longfin smelt are discussed
32 in detail in Appendix 5.D, *Contaminants*.

33 Toxicity testing demonstrated that the levels of herbicides used in DBW's programs were several
34 orders of magnitude less the impact levels on delta smelt (Riley and Finlayson 2004). For delta
35 smelt, the no observable effects concentration was several orders of magnitude greater than the
36 maximum herbicide concentrations used for each herbicide except diquat, confirming a favorable
37 margin of safety. Toxicity values for longfin smelt were expected to be similar, with a similar margin
38 of safety. Based on testing that showed a low margin of safety for diquat, use of this herbicide is
39 avoided when smelt are present. These results were supported by independent studies conducted
40 by the Aquatic Pesticide Monitoring Program of the San Francisco Estuary Institute (Siemering
41 2006).

1   The proposed CM13 would use the protocols and herbicide formulations developed by DBW and
2   would treat a similar amount of acres; therefore effects would be the same as those of the existing
3   permitted program and thus are not likely to adversely affect delta smelt and longfin smelt.

4   ### *Salmonids*

5   The potential effects of herbicide use for IAV control on salmonids are discussed in Appendix 5.D,
6   *Contaminants*. Listed salmonids could be exposed to herbicides during the out-migration of smolts
7   in spring and summer and the up-stream migration of adults (National Marine Fisheries Service
8   2006) if the out-migration periods coincide with herbicide treatments. Out-migration of winter-run
9   Chinook smolts occurs September to April, spring-run Chinook smolts migrate October through
10   April; late fall-run Chinook smolts October to February; and Fall-run Chinook smolts April to July
11   (California Department of Boating and Waterways 2006: Appendix 5.D). Smolt would be present in
12   the Delta when treatment of *Egeria* is most effective—early spring (April) when *Egeria* growth is
13   most rapid—and would be using shallow water areas for foraging and shelter, areas where *Egeria* is
14   present. Although juvenile salmonids have not been found to use dense *Egeria* stands (McGowan
15   1998; Grimaldo et al. 2012), they could occur at the margins and could be exposed to herbicide
16   treatments. Similarly, juvenile salmonids are unlikely to use dense water hyacinth stands because of
17   the low levels of DO in the water column beneath the mat of vegetation (National Marine Fisheries
18   Service 2006). Adult salmonids are not expected to be adversely affected by herbicide treatments
19   because they use deep water channels that are not infested by IAV and would not be treated
20   (National Marine Fisheries Service 2006).

21   The percentage of the population that could be adversely affected by exposure to these herbicides is
22   uncertain, and is a factor of overlap in time (herbicide treatments occurring during salmonid
23   migration periods) and space (probability of salmonids occurring within dense *Egeria* and water
24   hyacinth infested areas). The proportion is likely to be low because field surveys show that
25   salmonids avoid dense IAV-infested areas, and is further reduced by timing restrictions to avoid
26   migration routes during the period when juvenile salmonids are out-migrating. Long-term effects
27   are unlikely because long-term exposure is unlikely: salmonids are expected to move away from
28   treatment areas, and herbicide concentrations are maintained for relatively short periods of time.

29   As with smelt, toxicity testing demonstrated that the levels of herbicide used in DBW's programs
30   were several orders of magnitude less than the impact levels on salmonids (Hosea 2005). These
31   results were supported by independent studies (Siemering and Hayworth 2005; Siemering 2006).
32   Based on testing that showed a low margin of safety for diquat, use of this herbicide is avoided when
33   salmonids are present are present.

34   The aquatic herbicide concentrations used by the DBW programs therefore are not likely to
35   adversely affect salmonids. The proposed CM13 would use the protocols and herbicide formulations
36   developed by DBW and would treat a similar amount of acres; therefore effects would be minor, and
37   there would be no adverse effects on aquatic life, including salmonids.

38   ### *Sturgeon*

39   The potential effects of herbicide use for IAV control on sturgeon are discussed in Appendix 5.D,
40   *Contaminants*. There are no toxicity data on effects of aquatic herbicides on green sturgeon, but
41   based on surrogate species, NMFS concluded that because the concentrations of herbicide used in
42   the DBW programs are low enough to prevent substantial mortality of fish and would be in small
43   areas and would dissipate, widespread adverse effects were not anticipated (National Marine

1   Fisheries Service 2006, 2007). This conclusion was supported by independent studies conducted by
2   the Aquatic Pesticide Monitoring Program (Siemering and Hayworth 2005; Siemering 2006), Based
3   on these findings, and because the proposed CM13 would use the protocols and herbicide
4   formulations already developed by DBW and would treat a similar amount of acres, adverse effects
5   on sturgeon from implementation of CM13 are not anticipated. It is not expected that critical habitat
6   would be affected by herbicide application because of the relatively rapid dissipation of herbicide in
7   the water column, the low bio-availability of herbicide in the sediment, and the low bioaccumulation
8   factor.

9   **Potential Adverse Effects of Invasive Aquatic Vegetation Control Treatments on Water Quality**

10 Covered fish could be affected by changes in water quality resulting from herbicide applications,
11 particularly reduced DO and increased detritus from the death and decay of large amounts of
12 treated vegetation. These potential effects were addressed in DBW's monitoring and research
13 reports and environmental documents, which summarized research findings and proposed
14 avoidance and minimization measures, including measuring and monitoring herbicide
15 concentrations at and downstream of the treatment sites and DO pre- and post-treatment and
16 postponing treatment or limiting the amount of acres treated if DO fell below specific levels.

17 Information on water quality effects observed during and after herbicide treatment comes from the
18 monitoring conducted by DBW. Results showed that potential adverse effects on DO caused by
19 decaying *Egeria* were reduced by the slow-acting nature of fluridone, which results in a gradual die-
20 off over 30 to 60 days; in addition, the flow rates through treated areas were found to replenish DO
21 (California Department of Boating and Waterways 2006). Similar results were found after water
22 hyacinth treatment—the limited amount of acres of water hyacinth treated at any one site avoided
23 adverse effects on DO.

24 Based on these findings, and because the proposed CM13 would use the protocols and herbicide
25 formulations developed by DBW and would treat a similar amount of acres, any increase in
26 particulate organic carbon (POC) and reduction in DO caused by treatment is expected to be similar
27 to those observed after previous control treatments, and would be localized and short-term. This
28 minor effect would be further reduced by fish moving away from any areas with reduced DO
29 (National Marine Fisheries Service 2007).

30 **Potential Changes in Predator-Prey Dynamics**

31 There is some potential for displacement of nonnative predatory fish from treated areas to
32 untreated areas, and removal of *Egeria* may increase the foraging efficiency of striped bass. These
33 changes have the potential to increase local predation on migrating salmonids in the short term until
34 relative distributions of predators and prey equilibrate (National Marine Fisheries Service 2007).
35 The initial effect on migrating juvenile salmonids could be moderate to severe in the short term, but
36 would quickly balance out as relative distribution equilibrates. For more information, see the
37 discussion in Section 5.F.5, *Fish Predation*.

38 **Potential for Other Invasive Aquatic Vegetation to Colonize after Target Invasive Aquatic**
39 **Vegetation Removal**

40 A potential risk of IAV control is that successful removal of IAV may open the door to colonization by
41 another IAV species, especially if environmental conditions have been altered to the point where
42 native species cannot thrive and other IAV species are already present. Indeed, Santos and

1   coauthors (2011) suggest that earlier colonization of the Delta by Eurasian water milfoil
2   (*Myriophyllum spicatum*) may have facilitated the later invasion of *Egeria*, a process termed
3   *invasional meltdown* (Simberloff and Holle 1999). Targeted removal of *Egeria* could in turn benefit
4   another invasive SAV species, such as Eurasian water milfoil, curlyleaf pondweed or hydrilla, or the
5   balance could shift toward native species. Factors such as water quality and nutrient levels,
6   differences in ecology and physiology between species, competition, species presence and
7   distribution, and even plant architecture may influence replacement dynamics after successful IAV
8   removal.

9   In the Delta, the pool of species that could replace dense *Egeria* stands includes native SAV species
10   as well as nonnative species, some of which are known to be invasive or potentially invasive.
11   However, *Egeria* is capable of reinvading treated areas (California Department of Boating and
12   Waterways 2006),

13   An extensive survey of SAV in the Delta conducted in 2007-2008 showed that SAV in the Delta is
14   composed of a mix of native and nonnative SAV species, albeit strongly dominated by *Egeria* (Santos
15   et al. 2011). Nonnatives included some potentially invasive species, as rated by Cal-IPC (2006):
16   Eurasian water milfoil (rated high), curlyleaf pondweed (*Potamogeton crispus*; rated moderate), and
17   Carolina fanwort (*Cabomba caroliniana*; not rated by Cal-IPC) (Santos et al. 2011). A very recent
18   invader, just at the point of becoming established in the Delta, is South American spongeplant
19   (*Limnobium laevigatum*; rated high-alert by Cal-IPC) (Akers 2010). Hydrilla, a highly invasive SAV
20   species, is not known to be present in the Delta, but is present in Clear Lake, which is connected to
21   the Delta via Cache Creek. Native SAV species present within *Egeria*-dominated SAV, albeit in small
22   amounts, included coontail (*Ceratophyllum demersum*), Canadian waterweed (*Elodea canadensis*),
23   longleaf pondweed (*Potamogeton nodosus*), sago pondweed (*Stuckenia pectinata*), and broadleaf
24   sago pondweed (*Stuckenia filiformis*) (Santos et al. 2011; Boyer 2012).

25   Removal of FAV may improve habitat conditions for SAV: in a presentation aptly titled, "Better the
26   devil you know than the devil you don't: submerged aquatic weed invasions in South Africa,"
27   Coetzee (2009) suggests that sites with dense nonnative FAV cover may be resistant to invasive SAV,
28   but removal of FAV cover can allow nonnative SAV to invade. There is some evidence from the Delta
29   that the successful removal of water hyacinth has created habitat for SAV, including *Egeria*—surveys
30   showed that 14% of the area cleared of water hyacinth became dominated by SAV or other FAV and
31   emergent species (Santos et al. 2009). Removal of water hyacinth also could create vacant water
32   surface that could allow a recently appearing invasive FAV species, South American spongeplant, to
33   establish and spread.

34   Environmental factors may influence succession because tolerances and responses to different
35   environmental variables vary between species. For example, native Canadian waterweed is known
36   to be depth-tolerant (Nichols and Shaw 1986), and in the Delta, it had a higher biomass at greater
37   depth (Santos et al. 2011). Additionally, like other native SAV species, it is less tolerant of higher
38   water temperatures (Santos et al. 2011) and does not compete well with nonnatives that grow
39   better at higher temperatures (Nichols and Shaw 1986). Three species in the Delta, Eurasian water
40   milfoil, curlyleaf pondweed, and Canadian waterweed, grew better at higher salinity levels (Santos
41   et al. 2011).

42   Sago pondweed is a native SAV species that forms extensive stands in Suisun Marsh and the West
43   Delta in conditions of higher salinity than the *Egeria*-dominated SAV of the central Delta. Research is
44   being initiated into the factors that control its distribution and growth, especially the role of salinity

1   in controlling the distribution of native versus nonnative SAV with the aim of predicting which
2   species will persist under different environmental conditions (Boyer 2012).

3   Hydrilla presents a serious potential risk, because growth experiments have shown that hydrilla
4   may outcompete *Egeria* under many conditions (Mony et al. 2007); for example, *Egeria* had lower
5   growth rate at high alkalinity than hydrilla (Kahara and Vermaat 2003 and others cited therein),
6   suggesting that *Egeria* appeared to be less effective at using bicarbonate than hydrilla.

7   In previous years, it appeared to be *Egeria* that recolonized treated areas (California Department of
8   Boating and Waterways 2006), but there is some anecdotal evidence that native aquatic plants are
9   able to colonize treated areas. In 2007, it appeared that in some areas the SAV species composition
10   did shift to other species, including natives (Santos et al. 2009). The native pennywort has been
11   observed to colonize areas where water hyacinth has been removed or died back (Toft 2000).

12   The species composition of recolonizing vegetation may also be a function of local availability of
13   propagules—which species recolonize might be in part be determined by which species already
14   exist adjacent to the treated areas. Sago pondweed may be able to reestablish quickly from tubers
15   that survive in the sediment after herbicide treatment has killed other SAV species (Ruch and
16   California Department of Boating and Waterways, Aquatic Weed Unit 2006; Santos et al. 2009).
17   There is also evidence, however, that *Egeria* may move into areas where water hyacinth has been
18   removed (Santos et al. 2011). Observations from the Delta also suggest that each year there are
19   shifts in cover in both directions between SAV and water hyacinth on the order of 6% to 30%,
20   suggesting that single-species management may not be the optimal approach (Santos et al. 2009).

21   Physical structure of the different species may affect how they interact. Coontail was the second
22   most abundant species in the 2007-2008 survey and was found to co-occur frequently with *Egeria*.
23   It grows entwined in the canopy of other species rather than anchored in the sediment—*Egeria* may
24   provide suitable anchoring structure, whereas the narrow-leaved native sago pondweed may not
25   provide effective anchoring (Santos et al. 2011). In the absence of the structure provided by *Egeria*,
26   the native coontail may not be able to recolonize.

27   The risk of IAV removal causing invasion and spread of other IAV species is moderate, and has been
28   observed to some extent following IAV treatments in the Delta. Improved understanding of the
29   environmental factors influencing the growth of different SAV and FAV species, both native and
30   invasive, will address this uncertainty, and has the potential to improve the ability to manipulate
31   environmental conditions to favor desirable SAV and FAV species.

5.F.4.3.2   CM20 Recreational Users Invasive Species Program

33   Under CM20, the Implementation Office will fund a Delta Recreational Users Invasive Species
34   Program designed to implement actions to prevent the introduction of new invasive species into the
35   Plan Area. Funding will be provided to implement the CDFW Watercraft Inspection Program and
36   reduce the spread of existing aquatic invasive species via recreational watercraft, trailers, and other
37   mobile recreational equipment used in aquatic environments in the Delta. It will do this primarily by
38   educating recreational users about the importance of avoiding further introductions of aquatic
39   invasive species and by instituting recreational watercraft inspections that directly reduce the risk
40   of invasive species introduction and proliferation.

41   One important component of an integrated invasive plant program is prevention, which
42   incorporates regulatory authority, risk analysis, knowledge of introduction pathways, and

1   inspections. Invasive aquatic plants such as hydrilla (not yet known to occur in the Delta) can be
2   fragmented and spread by boats and trailers moving between watersheds (California Department of
3   Fish and Game 2008). Specifically, efforts that prevent the transport of invasive species by requiring
4   recreational boats to be properly cleaned, drained, and dried after leaving a water body that could
5   harbor invasive plant species are considered beneficial.

6   ### 5.F.4.3.2.1   Benefits and Risks

7   The boat inspections will direct effort to one of the important routes by which IAV species are
8   moved between water bodies. Controlling the introduction of invasive aquatic plant species,
9   especially hydrilla, or the further spread of any existing invasive aquatic plant species, would benefit
10 aquatic natural communities and covered fish in the Plan Area. In addition, the inspections and
11 related public education will inform the public on the threats posed by IAV and how to recognize
12 invasive species, thus increasing the level of awareness and vigilance. The invasion route of the two
13 predominant IAV species in the Delta now, *Egeria* and water hyacinth, was not via watercraft, but as
14 a result of aquarium and landscape use, so it is doubtful that a watercraft inspection program could
15 have prevented their introduction. However, efforts to increase public awareness of the negative
16 effects of IAV and the different routes by which an invasive species could be introduced and spread
17 in the Delta might help to prevent this type of introduction in the future. There would be no risk to
18 the aquatic natural community in the Plan Area from implementation of CM20 and there would be
19 benefit from increasing public awareness of the negative environmental damage caused by IAV and
20 the public's role in preventing future introduction and spread.

21 # 5.F.4.4   Uncertainties and Research Needs

22 ## 5.F.4.4.1   Uncertainties

23 Uncertainties of effects are related to both lack of knowledge, which can be addressed by research,
24 and unpredictability, which results from the highly variable and complex nature of the Delta
25 ecosystem.

26 ### 5.F.4.4.1.1   Potential for Success

27 This discussion will review control efforts to date for *Egeria* and water hyacinth in the Delta, and
28 examples of other existing and potential IAV species, to attempt to answer the question: Can IAV in
29 the Delta, especially a species as widespread as *Egeria*, be effectively controlled?

30 #### *Egeria*

31 The history of control efforts for *Egeria* in the Delta and the increase of *Egeria*-dominated SAV over
32 the years are discussed in Section 5.F.4.2.3.2. In summary, the early years of the DBW EDCP were
33 limited by resources, rather than by biological or ecological factors, and coincided with the rapid
34 expansion of *Egeria* throughout the Delta at an annual growth of about 10 to 15%—the program
35 appeared to be too little, too late and was not gaining ground against a rapidly expanding target.
36 However, the success of the Franks Tract management focus in 2007-2008 shows that effective
37 control of quite large areas (on the order of 2,750 acres over 2 years) with early season herbicide
38 treatment is possible, and significant reductions in SAV cover were achieved, although this was
39 offset by continuing spread elsewhere. However, there is a suggestion that *Egeria* may be slowing

1   down, perhaps because it is close to occupying most of the suitable habitat in the Delta (Hestir pers.
2   comm. cited in Baxter et al. 2010).

3   Assuming a continued 10% annual growth rate, the acreage that would need to be treated to
4   maintain the status quo would be about 1,000 to 1,500 acres per year, slightly less than the low
5   estimate of the proposed treatment acreage under CM13, which at 1,700 acres, would represent a
6   17% reduction in the current acreage of SAV. The high estimate, 3,400 acres/year would represent a
7   34% reduction, which would make significant inroads into the current SAV acreage.

8   There seems little doubt that a sustained program that treated at least 1,500 to 1,700 acres annually
9   using application timings, protocols, and experience developed by the existing control programs,
10   and that was able to treat source populations, could result in a significant decrease in the extent of
11   *Egeria* across the Delta. As has been observed over the course of the WHCP, as the total infested
12   acreage declines with sustained treatment, the amount required to be treated also decreases.

13   Although the details on apportioning effort between source populations and ROAs have yet to be
14   worked out, there seems little doubt that applying the principles of early detection and rapid
15   treatment of early colonizing *Egeria* when it first appears in a new ROA would be effective.

16   **Water Hyacinth**

17   The history of control efforts for water hyacinth in the Delta and its increase over the years were
18   discussed in Section 5.F.4.2.3.3. From a high of 1,000 acres in 1981, just before the DBW control
19   program began, water hyacinth was reduced to an estimated 139 acres in 2008, and the program
20   can be considered successful in controlling water hyacinth across the Delta (Santos et al. 2009;
21   Baxter et al. 2010). There is little uncertainty that a sustained program of herbicide treatment was
22   effective at controlling water hyacinth.

23   **Hydrilla**

24   The absence of hydrilla from the Delta now is a testament to the success of CDFA's aggressive
25   Hydrilla Eradication Program, which is mandated to eradicate, not control, hydrilla in California.
26   This approach was determined necessary to protect the state's water systems from the
27   environmental and economic effects of this highly invasive species. After each hydrilla outbreak, a
28   Hydrilla Science Advisory Panel is convened; these panels have always found eradication to be
29   feasible (Akers 2010). To date, there have been 29 hydrilla introductions and 20 successful
30   eradications; no new infestation have been found since 2005 (Akers 2010). The Hydrilla Eradication
31   Program uses an integrated pest management approach, with manual removal, small-scale dredging,
32   lining of water bodies, biological control, and aquatic herbicides.

33   One of the largest infestations in California is in Clear Lake, which is connected hydrologically to the
34   Delta, and like the Delta has a high level of recreational boat use, so there is potential for hydrilla to
35   spread to the Delta via both routes. Covering 739 acres of Clear Lake at its worst, after several years
36   of herbicide treatment and intensive surveys, by 2010 only a handful of plants was detected. The
37   successful eradication of hydrilla from the Chowchilla River and Eastman Lake in central California
38   also demonstrates that a successful outcome can be achieved given a large enough effort (Maly
39   2006).

40   Aware of the threat to the Delta (Leavitt 2002), and committed to early detection and rapid
41   response, CDFA since the mid-1980s has conducted an annual survey of the Delta and lower reaches
42   of tributaries for hydrilla. The surveys are extensive and thorough—larger waterways, such as OMR,

1   major canals, and many of the major sloughs, are surveyed from motorboats; marinas, launch ramps,
2   and some of the smaller channels and sloughs are surveyed by canoe, kayak, or airboat. No hydrilla
3   has been detected.

4   The success of the hydrilla program state-wide shows that, (1) given the legislative authority,
5   sufficient and consistent resources, and effort, in partnership with several cooperating agencies and
6   organizations, eradication of a highly invasive aquatic weed is possible; and (2) early detection
7   involving Delta-wide monitoring for hydrilla is a feasible effort as part of an integrated invasive
8   aquatic vegetation program. There is continuing uncertainty on whether hydrilla could spread to the
9   Delta, but continued monitoring reduces the level of uncertainty. In addition, the effects of hydrilla,
10   should it establish and spread in the Delta, and uncertain.

11   **South American Spongeplant**

12   This potential invader first was detected in 2004 in the San Joaquin River in Fresno County and
13   immediately was recognized to present a significant threat, similar to water hyacinth but with a
14   higher ability to reproduce and spread (Akers 2010). Its ability to produce abundant seed that can
15   remain viable for several years and tiny seedlings that are easily moved by water currents makes
16   early detection and rapid response very important for this species. Eradicating small infestation
17   before they can reproduce and spread is vital. Monitoring and control have been aggressively
18   implemented by giving responsibility for spongeplant to the Hydrilla Eradication Program. Since
19   2004, small infestations have appeared around the state. In late December 2007, a patch of
20   spongeplant was found on the east edge of Decker Island on the Sacramento River. A winter storm
21   appeared to have eradicated the patch, but it reappeared in 2009 and has been spreading slowly
22   east and south. A recently passed Assembly Bill (AB) 1540 amends Section 64 of the Harbors and
23   Navigation Code, which designated DBW as the lead state agency for *Egeria* and water hyacinth
24   control, by adding South American spongeplant. AB 1540 recognizes that early stage treatment of
25   South American spongeplant will reduce the long-term cost and effort to keep the spongeplant from
26   spreading in the Delta. Resource limitations initially hampered efforts to eradicate this infestation
27   (Akers 2010), increasing uncertainty that this species could establish and spread rapidly, but the
28   recent legislation provides legal authority for funding beginning Jan 1, 2013, to address spongeplant
29   in the Delta and its tributaries.

30   **Other Species**

31   The combined knowledge, experience, and vigilance of the various agencies, research organizations,
32   and weed control programs in and around the Delta—DBW, U.S. Department of Agriculture,
33   Agriculture Research Service (USDA-ARS), CDFA, Center for Spatial Technologies and Remote
34   Sensing (CSTARS), and the Bay Area Early Detection Network (BAEDN), a partnership of regional
35   land managers, invasive species experts, and concerned citizens—enable rapid detection and
36   effective early response to any new Delta invader. In addition, CM20 should be effective in
37   preventing new IAV species from gaining a foothold in the Delta. The introduction of nonnative and
38   potentially invasive species into the Delta is a continuing process, and there is considerable
39   uncertainty regarding which species are introduced, where, and when. Uncertainties exist to some
40   extent in predicting whether a specific species will become invasive or not, and currently species are
41   present in low amounts in the Delta that are problematic elsewhere, e.g., Eurasian water milfoil. The
42   increased level of vigilance and improved ability to develop predictive tools help to reduce the level
43   of uncertainty and generate positive results.

1   **5.F.4.4.1.2   Overlap of Delta and Longfin Smelt and Invasive Aquatic**
2   **Vegetation–Infested Areas**

3   One of the uncertainties is the extent of overlap between the distribution of covered smelt species
4   and the areas of dense IAV infestation, particularly the extent of overlap between delta smelt
5   spawning areas and IAV. The central distribution of small delta smelt ranges from about 70 to
6   130 km from the Golden Gate from April through July and for large delta smelt, 75 to 100 km from
7   May through July (Dege and Brown 2004), clearly within the range of *Egeria*. However, on a local
8   level, uncertainty exists on habitat use—larval and juvenile delta smelt have been collected from
9   nearshore habitats, including marsh edge and offshore habitats in the low salinity zone (LSZ)
10   (Grimaldo et al. 2004; Bennett and Burau 2011); however, other studies indicate that juvenile delta
11   smelt are found predominantly in open channel areas and are not found near shore (Nobriga et al.
12   2005).

13   The distribution of longfin smelt is more westerly and occurs for a shorter time period; small longfin
14   smelt are located about 60 to 90 km from the Golden Gate from April through May and large longfin
15   are located 50 to 85 km from the Golden Gate from April through July (Dege and Brown 2004).
16   Although longfin smelt use areas in the lower Sacramento and San Joaquin Rivers, they spawn
17   earlier than delta smelt and do not remain in this part of the Delta nearly as long as do delta smelt
18   (Nobriga et al. 2004). IAV occurs in less saline areas, e.g., upstream of the Antioch area (about 85 km
19   from the Golden Gate). These distributional patterns indicate that removal of SAV would tend to
20   have a stronger beneficial effect on delta smelt than on longfin smelt.

21   **5.F.4.4.1.3   Overlap of Salmonids and Invasive Aquatic Vegetation–**
22   **Infested Areas**

23   Uncertainties exist on the overlap between juvenile salmonids and IAV. Prioritization of areas for
24   treatment can be improved with better understanding of the relative distribution and habitat use by
25   juvenile salmonids in the Delta. Juvenile salmonids use the Delta both as a migration corridor and as
26   rearing and foraging habitat. Mortality of juvenile salmon is high in Cache Slough (Perry and Skalski
27   2009), but that could be mitigated by IAV removal leading to decreased predator abundances.
28   Extensive *Egeria*-dominated SAV infestations in main migration pathways likely increase predation
29   risk.

30   **5.F.4.4.1.4   Post-Treatment Conditions**

31   **Foodweb**

32   The effects on the foodweb from controlling IAV are uncertain. Removal of dense IAV may change
33   productivity or food availability for covered species. The productivity of *Egeria* and its contribution
34   to the foodweb as a primary producer in the Delta are largely unknown. Recent research has shown
35   that the epiphytic algae on *Egeria* are grazed upon by amphipods that were a dominant component
36   of the diet of late juvenile fish (Grimaldo et al. 2009b). Whether native SAV species support a similar
37   epiphytic algae and grazing amphipods is unknown. It is uncertain how the invertebrate assemblage
38   would change with control of *Egeria* and what impact this would have on food availability for
39   juvenile fish. Water hyacinth in the Delta supports a higher density of a nonnative amphipod not
40   prevalent in fish diets compared with the native water pennywort, which supports a higher density
41   of a native amphipod favored by fish. Removal of water hyacinth would remove the habitat for these
42   invertebrates. Some research evidence suggests that native SAV and FAV species may support a

1 higher proportion of native invertebrates that are favored by and available to native fish. This
2 suggests that a shift from nonnative to native SAV/FAV could change the invertebrate assemblage
3 and therefore affect organisms higher up the foodweb. Uncertainty also exists in the response of
4 phytoplankton to increased light in the water column that could result from removal of *Egeria*.

5 **Succession/ Replacement Dynamics**

6 There is uncertainty about which aquatic plant species, native or nonnative, could colonize the
7 newly treated habitat. There is evidence from the Delta and elsewhere that removing one IAV
8 species can shift the balance, allowing a different IAV species to invade. There is also evidence that
9 IAV removal can shift the balance to native species. Although the environmental tolerances of many
10 aquatic plant species are known, the factors that determine which species will replace the IAV that
11 has been treated are still poorly understood, and there is high uncertainty in predicting the direction
12 of succession at each site after treatment. Research is being initiated into the factors that control
13 distribution and growth of native pondweeds, especially the role of salinity in controlling the
14 distribution of native versus nonnative SAV with the aim of predicting which species will persist
15 under different environmental conditions (Boyer 2010).

16 **Turbidity**

17 There is considerable quantitative uncertainty in the relationship between IAV and turbidity,
18 especially in predicting the changes in turbidity that could result from IAV control. Although *Egeria*
19 is recognized as a "system engineer" that is very effective at reducing local turbidity, another major
20 factor is the sediment supply. The amount of sediment reaching the Delta has decreased in the latter
21 half of the twentieth century (Wright and Schoellhamer 2004; Cloern et al. 2011). This suggests that,
22 despite removal of *Egeria*, turbidity levels may not be increased to pre-infestation levels simply
23 because overall sediment input is lower, and as a result, the desired state change from a low
24 turbidity–high SAV state to a high turbidity–low SAV state may not be achieved.

25 *Microcystis*

26 The decay of large amounts of IAV after control treatment has the potential to cause substantial
27 releases of nitrogen, carbon, and phosphorus, which could trigger rapid growth of *Microcystis*.
28 However, post-treatment monitoring in the Delta has shown that the treatments used to control
29 *Egeria* do not produce a sudden release of nutrients because of the slow effects of fluridone—*Egeria*
30 dies and decays slowly over the course of several weeks, and nutrient releases therefore are gradual
31 without adverse effects on water quality (California Department of Boating and Waterways 2006).
32 Although shredding of water hyacinth in the Delta produced a large amount of decaying plant matter
33 and short-term increases in nitrogen and phosphorus, local effects varied depending on site-specific
34 hydrology, and broader effects were limited (Greenfield et al. 2007). These results suggest that this
35 effect of SAV control would not have adverse effects on water quality that would trigger *Microcystis*
36 bloom.

37 ## 5.F.4.4.2   Research Needs

38 ### 5.F.4.4.2.1   Ecology and Biology of Invasive Aquatic Plant Species in the Delta

39 Knowledge of seasonal growth rates, phenology, reproduction, and resource allocation of the major
40 IAV species of concern in the Delta provides guidance on the most effective methods and times of
41 the year for control treatments, aiming to apply control methods when the plants' ability to recover

1   is lowest. Recent and ongoing research on *Egeria* (e.g., Pennington and Sytsma 2009) and water
2   hyacinth (Spencer and Ksander 2005) have provided useful information in that regard—for
3   example, knowing that *Egeria* in the Delta has a secondary growth peak late in the season and does
4   not die back in the Delta's mild water temperatures (Pennington and Sytsma 2009), surveys in the
5   fall are effective in identifying concentrations of *Egeria* to target in early spring treatments (Santos
6   et al. 2011).

7   Continuing research on biological control is required to alleviate the concerns about toxicity effects
8   of herbicide use. Biological control has been successful against water hyacinth, particularly in the
9   southeast United States (Center et al. 2002). The CDFA released water hyacinth–eating weevils
10 (*Neochetina eichhorniae* and *N. bruchi*) and a moth (*Sameodes albiguttalis*) at selected sites in the
11 Delta. Only *N. eichhorniae* established but survived at densities too low to affect water hyacinth, in
12 part because of cool winter temperatures (California Department of Boating and Waterways 2003),
13 and perhaps because of pathogens; additional studies are needed to investigate whether they have
14 been infected by a pathogen.

15 DBW recently began releasing the water hyacinth water hopper (*Megamelus scutellaris*) at three
16 sites in the Delta (California Department of Food and Agriculture 2011). A fungus isolated from
17 *Egeria* in its native range, a species of fusarium, has shown promise in laboratory experiments but
18 has not yet been tested under field conditions. USDA-ARS and collaborators conduct surveys within
19 the native ranges of IAV species and collect and evaluate potential biological control organisms.
20 They recently evaluated the potential of a leaf mining shore fly (*Hydrellia* sp. 1) as a biological
21 control agent for *Egeria* in the Delta, and found that the fly could defoliate *Egeria* both in the
22 laboratory and under field conditions, and appears to be a good candidate for introduction (Cabrero
23 Walsh et al. 2012).

24 One of the risks associated with biological control is that the organism may attack closely related
25 native species. The water hyacinth–eating weevils prey on all members of the pickerelweed family
26 (Pontederiaceae), but all but one species in California is nonnative, and the only native species,
27 grassleaf mudplantain (*Heteranthera dubia*) does not occur in the Delta; the closest known
28 occurrence is in Colusa County (Calflora 2012).All candidate biological control agents undergo
29 extensive testing against a range of nontarget species, including all native species closely related to
30 the target invasive species and the risk of the agent attacking a nontarget species is carefully
31 evaluated.

5.F.4.4.2.2   Overlap of Delta Smelt and Invasive Aquatic Vegetation–Infested Areas

34 The overall distribution of delta smelt is known, but habitat use and rearing areas are less certain.
35 Spawning areas are not known—sampling of larval smelt suggests spawning occurs in the
36 Sacramento River, Barker, Lindsey, Cache, Georgiana, Prospect, Beaver, Hog, and Sycamore sloughs,
37 in the San Joaquin River off Bradford Island including Fisherman's Cut, False River along the shore
38 zone between Frank's and Webb tracts, and possibly other areas (Wang 1991) and Recent CDFW
39 sampling has suggested that spawning is often centered in Cache Slough and the lower end of the
40 Sacramento Deepwater Ship Channel (California Department of Water Resources and California
41 Department of Fish and Game 2007). These areas are within the range of *Egeria*, and research
42 should continue to attempt to discover the spawning locations and habitats, and enable the overlap
43 between spawning and rearing areas and dense *Egeria*-dominated IAV to be quantified.

1 ### 5.F.4.4.2.3　　Overlap of Salmonids and Invasive Aquatic Vegetation–
2 ### Infested Areas

3 Research on habitat use and movements of juvenile salmonids in the Delta would improve
4 understanding of use of shallow water habitats typically infested with dense *Egeria*-dominated SAV.
5 Quantification of this habitat use would improve the ability to predict and quantify potential adverse
6 effects on salmonids from herbicide treatments.

7 The Delta Passage Model (DPM) (Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*) and radio
8 telemetry studies (e.g., San Joaquin River Group Authority 2011) could be used to identify important
9 migration corridors or use of areas with IAV.

10 ### 5.F.4.4.2.4　　Post-Treatment Conditions

11 **Foodweb**

12 Research on the extent to which *Egeria* is an important primary producer and contributes to the
13 foodweb should be continued. *Egeria* supports invertebrates that are important prey for native fish
14 and also supports epiphytic algae that play a basal role in littoral foodwebs and research has begun
15 to quantify the contribution to the wood web (Grimaldo et al. 2009b). However, the effects of *Egeria*
16 removal on these components has not been quantified, nor has the nature and extent to which
17 native SAV, were it to replace *Egeria*, would contribute to foodwebs. Research has recently begun on
18 comparing the epifaunal invertebrate assemblages supported by native sago pondweed stands
19 compared with *Egeria* (Rubissow Okamoto 2012). Another important research topic is the extent to
20 which phytoplankton growth responds to removal of IAV.

21 **Succession/ Replacement Dynamics**

22 Manipulation of water quality and other environmental factors to reduce suitability for IAV while at
23 the same time improving environmental conditions for native species. The environmental tolerances
24 of some IAV are relatively well known, e.g. the salinity tolerance of *Egeria* and water hyacinth. It
25 might be feasible to create conditions that favor the colonization and growth of native species rather
26 than IAV, especially in restoration areas. Extensive stands of sago pondweed (*Stuckenia pectinata*)
27 and fineleaf pondweed (*S. filiformis*) occur in the shallow subtidal zone in Suisun Bay and the West
28 Delta (Boyer 2012). Current research is investigating the environmental factors that affect the
29 growth and distribution of native pondweeds, and suggests the potential for manipulating
30 environmental conditions to enhance conditions for native SAV while reducing suitability for IAV
31 (Boyer 2010; Boyer 2012; Rubissow Okamoto 2012).

32 **Turbidity**

33 The response of turbidity to the removal of IAV, especially *Egeria*–dominated SAV, is one of the
34 largest uncertainties. Continued monitoring post-treatment of turbidity at sites where IAV has been
35 treated, short- and long-term would help to increase understanding of the relationship between SAV
36 removal and turbidity changes. In addition, field experiments on IAV removal at sites with different
37 patterns of sediment input, suspension, and currents (water and wind) would be useful.

38 ### 5.F.4.4.2.5　　Performance/Efficacy Monitoring

39 Recent and current research should continue to investigate improved methods of surveying and
40 measuring the extent of IAV infestations before and after herbicide treatment to provide fast and

1 efficient survey over large areas. Methods that provide results quickly are an important part of an
2 adaptive management program that would track the effectiveness of each treatment and help to
3 decide whether follow-up treatments were necessary. Recent innovations include the use of high
4 resolution hyperspectral satellite imagery combined with automated image analysis programs that
5 can quickly provide estimates of the areal extent of *Egeria* and water hyacinth over large areas of the
6 Delta (Ustin 2008) and sonar transducer surveys to assess the biovolume of *Egeria* in the water
7 column.

8 Post-treatment monitoring programs also should focus on two major areas relevant to the adverse
9 effects of IAV on covered fish populations: turbidity and nonnative predatory fish.

10 In addition to measurements of water quality, monitoring should include surveys before and after
11 treatment to determine the abundance and distribution of nonnative predatory fish. Sampling sites
12 for a treated region should include vegetated areas to be treated (before and after), untreated areas,
13 and nonvegetated sites to examine whether predatory fish population abundance or local
14 distribution has changed.

15 Post-treatment monitoring should be designed to detect *Microcystis* blooms and relate that to water
16 quality and hydrodynamic parameters. Finally, long-term monitoring should track the development
17 and succession of the aquatic plant community and the fish assemblage that develops following
18 treatment.

5.F.4.5   Conclusions

19

20 **The control of invasive submerged aquatic vegetation (CM13) should reduce local predation**
21 **mortality of covered fish species by removing habitat for predators and increasing turbidity**
22 **locally.**

23 IAV control should benefit covered fish species that use shallow-water habitats (habitats prone to
24 IAV growth) like salmonids and splittail, but should have a minor beneficial effect on pelagic fishes
25 like delta smelt and longfin smelt. Control of IAV, especially *Egeria*, is expected to enhance natural
26 ecosystem functions by removing ecologically dominant species that provide habitat and cover for
27 nonnative predatory fish such as largemouth bass. Predation on juvenile salmon, steelhead, and
28 splittail in the migration corridor can be significant; for example, juvenile Chinook salmon
29 experience predation by largemouth bass lurking in invasive SAV. Controlling IAV is expected to
30 locally reduce densities of largemouth bass, but conversely could enhance open water conditions
31 favored by pelagic predators such as striped bass.

32 Turbid conditions are important for delta smelt migration, spawning, and cover, but turbidity in the
33 Delta is lower than it was 30 to 40 years ago. Dense stands of IAV can reduce turbidity locally by
34 filtering sediment from the water and preventing resuspension (Hestir et al. 2010b). IAV control
35 would help maintain turbidity in restored habitats and potentially contribute to increased turbidity
36 in adjacent habitats invaded by *Egeria*. IAV removal alone would be insufficient to restore Delta-
37 wide turbidity to former levels because of overall reductions in sediment supply. Local increases in
38 turbidity potentially could improve conditions for delta smelt by improving concealment from visual
39 predators like largemouth bass and striped bass. The degree of benefit is uncertain and depends
40 both on the magnitude of turbidity increase and on how much control predation by these species
41 exerts on delta smelt population.

1 **The control of invasive aquatic vegetation (CM13) should increase food consumption by covered**
2 **fish species.**

3 Food consumption by delta smelt and longfin smelt larvae and juveniles is expected to increase if the
4 increased turbidity that would result from removing or reducing invasive SAV was a long-term
5 effect that reached the thresholds required to change the behavior of smelt. A certain concentration
6 of suspended particles seems to be necessary for proper feeding in young delta smelt—the larvae do
7 not feed in water that is too clear. The role and importance of turbidity for longfin smelt feeding
8 efficiency are not as well-known as they are for delta smelt. Understanding of the amount of overlap
9 between invasive SAV treatment areas and delta smelt and longfin smelt food areas is improving,
10 but overlap may be low for longfin smelt. However, it is known that areas currently occupied by
11 invasive SAV are not suitable for delta smelt; therefore removal of invasive SAV may help to restore
12 and maintain suitable habitat conditions in restored areas.

13 In addition to facilitating feeding by delta smelt and longfin smelt, removal of dense stands of IAV
14 has the potential to increase availability of pelagic food (phytoplankton, zooplankton) near
15 treatment locations by increasing light levels below vegetation. Dense IAV blocks light penetration
16 into the water column. IAV control allows greater light penetration in the water column, leading to
17 greater phytoplankton productivity, which in turn leads to greater productivity of zooplankton that
18 constitute prey for a variety of covered fish species, primarily smelts and juvenile salmonids. Dense
19 IAV canopies reduce light penetration through the water column more than would the anticipated
20 increases in water turbidity resulting from IAV removal, and as a result, it is anticipated that IAV
21 removal would lead to an increase in phytoplankton productivity. Additionally, control of IAV and
22 the restoration of native aquatic plant communities in treated areas are expected to increase the
23 quantity and quality of habitat suitable for some prey resources (such as crustaceans, annelids,
24 mollusks, fish, and midges) important to green and white sturgeon. SAV removal and control thus
25 would lead to a net increase in food availability for these covered fish species.

26 **The control of invasive submerged aquatic vegetation (CM13) should increase the amount of**
27 **spawning and rearing habitat for covered fish species.**

28 Dense patches of invasive SAV physically obstruct covered fish species' access to habitat for
29 spawning and rearing. Removal of invasive SAV is expected to increase the availability of freshwater
30 spawning habitat for longfin smelt in the Delta (spawning occurs where average water temperatures
31 are 10 to 12°C from mid-December to April). There is no indication, however, that the delta smelt
32 population is limited by the amount of suitable spawning habitat area because they spawn
33 throughout the Delta in different years. Removal of dense stands of *Egeria* from channel edge and
34 shallow-water habitats is expected to increase the amount of suitable rearing and migration habitat
35 for juvenile salmonids and splittail.

5.F.5   Fish Predation

5.F.5.1   Ecological Effect Pathways

38 Predation is a natural process, but its extent and effects can change when established predator-prey
39 relationships are disrupted by environmental changes or species introductions (Baxter et al. 2010).
40 Aquatic ecosystems can be substantially altered by introduced predators (e.g., Brown and Moyle
41 1991; Goldschmidt et al. 1993) and changes in established predator-prey relationships (e.g.,

1   Carpenter et al. 2001; Frank et al. 2005; Estes et al. 2011). Changes in physical habitat structure,
2   such as IAV stands or water diversion intakes, can provide increased holding and ambush stations
3   for predators (Gaines and Martin 2002). Elevated predation rates are a potential indirect effect of
4   water diversion operations (Brown et al. 1996) and may be a potential hindrance to shallow-water
5   habitat restoration (Brown 2003; Nobriga and Feyrer 2007). For example, in the upper Sacramento
6   River, predation by Sacramento pikeminnow on juvenile Chinook salmon at large diversion
7   structures such as the Red Bluff Diversion Dam and the GCID intakes have been identified as one
8   cause of elevated mortality in juvenile Chinook salmon (Vondracek and Moyle 1983; Vogel et al.
9   1988; Vogel 2008).

10 Increased predation rates have been identified as a stressor for juvenile Chinook salmon (Good et al.
11 2005; Moyle 2002; National Marine Fisheries Service 2009), steelhead (Clark et al. 2009; National
12 Marine Fisheries Service 2009) and delta smelt (Baxter et al. 2008). Modeling by Lindley and Mohr
13 (2003) suggested that increases in the striped bass population could substantially reduce the
14 population viability of winter-run Chinook salmon. Statistical modeling by MacNally and coauthors
15 (2010) documented a weak negative relationship for largemouth bass and delta smelt. Delta smelt
16 life cycle modeling also points to predation as a negative factor (Maunder and Deriso 2011)
17 (Appendix 5.G, *Fish Life Cycle Models)*. The functional response of fish populations to predation
18 pressure, however, is not easy to predict and is likely to vary depending on species and ecological
19 context (Mather 1998; Durand 2008; Nobriga et al. 2011).

5.F.5.1.1.1   Predation in Aquatic Ecosystems

21 The pelagic organism decline conceptual model hypothesized that predation effects in the Delta
22 have increased as a result of increased populations of pelagic and inshore predatory fishes (Baxter
23 et al. 2010). Top-down forcing by predation has been suggested as one factor that, synergistically
24 with other sources of mortality, could be limiting the production of covered fish species (Baxter et
25 al. 2010). Top-down forcing and indirect interactions can have wide-reaching effects that cascade
26 through the ecosystem, in sometimes unpredictable patterns (Vander Zanden et al. 2006; Estes et al.
27 2011). In the Delta, it may be that nonnative prey (e.g., silverside, threadfin shad) maintain
28 nonnative predator populations (e.g., striped bass, largemouth bass) at high levels, causing
29 artificially high rates of predation on native fish. Similarly, ocean-based prey may maintain the adult
30 population of anadromous striped bass during their ocean phase (Loboschefsky et al. 2012). Fish eat
31 what can fit in their mouths, so diet shifts as fish grow from small juveniles consuming zooplankton
32 and fish larvae, to large juveniles and adults consuming even larger fish. In fact, young age classes of
33 piscivorous fishes may exert considerable predation pressure due to their great numbers (Kitchell et
34 al. 1997; Loboschefsky et al. 2012). Cannibalism is common in striped bass and can maintain
35 predator populations even as prey populations decline (e.g., Nile perch [Kitchell et al. 1997]).
36 Finally, there is intraguild predation by other small fish. Silversides have been hypothesized to be a
37 competitor and possibly a predator of delta smelt eggs and larvae (Bennett 2005).

38 The relative strength of biotic interactions and abiotic conditions in structuring aquatic
39 communities can vary depending on the spatial and temporal dynamics of disturbance regimes.
40 Benign or predictable physical environments are thought to be more conducive to development of
41 stronger biotic interactions (Peckarsky 1983; Poff and Ward 1989). One hypothesis of the pelagic
42 organism decline is that reduced variability in environmental conditions of the estuary may have
43 exacerbated predation effects, although there is no clear evidence that such changes have been
44 abrupt enough to account for the decline of pelagic species such as delta smelt, longfin smelt, and
45 striped bass (Baxter et al. 2010). Temporal shifts can occur in the relative importance of biotic and

1   abiotic mechanisms, so that "top-down" and "bottom-up" forces work in concert but at disparate and
2   time-varying rates (Power et al. 1988; Alpine and Cloern 1992).

3   Natural, co-evolved piscivore-prey systems typically have an abiotic production phase and a biotic
4   reduction phase each year (e.g., Rodriguez and Lewis 1994). Changing the magnitude and duration
5   of these cycles greatly alters their outcomes (Meffe 1984). Generally, the relative stability of the
6   physical environment affects the length of time each phase dominates and thus the importance of
7   each.

8   Historically, in the Bay-Delta estuary, the period of winter-spring high flow was the abiotic
9   production phase, when most species reproduced. The biotic reduction phase probably
10   encompassed the low-flow periods in summer and fall. This pattern has been observed on floodplain
11   systems such as the Yolo Bypass and Cosumnes River (Feyrer et al. 2006; Moyle et al. 2007). Multi-
12   year wet cycles probably increased (and still do) the overall "abiotic-ness" of the estuary, allowing
13   populations of all species to increase. Drought cycles likely increased the estuary's "biotic-ness"
14   (Livingston et al. 1997), with low reproductive output and increased effect of predation on
15   population abundances. Flow management in the San Francisco Estuary and its watershed has
16   reduced flow variation (Moyle et al. 2010) and probably affected magnitude and duration of abiotic
17   and biotic phases (Nobriga et al. 2005).

18   Knowledge of the strength of ecosystem interactions is necessary when attempting to manage the
19   abundance of a particular ecosystem constituent. The consequences of a single-species focus may be
20   counterintuitive and potentially counterproductive (Wiese et al. 2008; Pine et al. 2009). For
21   example, on the Columbia River a predatory bird control program has been implemented to protect
22   migrating juvenile salmon (Wiese et al. 2008). However, modeling suggested that one consequence
23   of removing or displacing piscivorous waterbirds (which feed on juvenile northern pikeminnow
24   when salmon are not present) could be increased pikeminnow abundance, which could theoretically
25   increase predation losses of juvenile salmonids (Wiese et al. 2008). Other examples of unpredictable
26   outcomes include lamprey control and trout stocking in the Great Lakes (Kitchell et al. 1994),
27   experimental manipulations in northern glacial lakes (Kitchell et al. 1994; Estes et al. 2011), bass
28   management in southeastern U.S. farm ponds (Pine et al. 2009), and trophic cascades in many
29   terrestrial and aquatic systems (reviewed by Vander Zanden et al. 2006; Pine et al. 2009; Estes et al.
30   2011).

5.F.5.1.2   Predators in the Bay-Delta

32   Fish are generally opportunistic foragers that consume whatever they can fit into their mouths.
33   Different life stages can have different diets, which affects both available energy for growth and
34   potential effects on prey species (Loboschefsky et al. 2012). For example, adult striped bass in the
35   Bay-Delta feed primarily upon fish, while younger striped bass rely more on lower-energy
36   invertebrate prey (Stevens 1966; Feyrer et al. 2003; Nobriga and Feyrer 2007). Diets vary widely
37   based on prey availability (Durand 2008). The prey choices of predators are inherently density-
38   dependent. Thus, predators tend to eat what is relatively abundant in the areas in which they are
39   foraging.

40   Common predatory fish species in the Delta are striped bass, largemouth bass, and to a lesser degree
41   Sacramento pikeminnow (Nobriga and Feyrer 2007). Other predators include white sturgeon (a
42   native fish), catfishes and other bass (nonnative). Smaller fish such as silversides can be important
43   predators on larvae. Piscivorous birds in the Bay-Delta (all native) include gulls, cormorants, terns,

1   diving ducks, herons, egrets, osprey and kingfishers. However, *CM15 Localized Reduction of*
2   *Predatory Fishes* does not include actions to affect piscivorous birds.

5.F.5.1.2.1   Striped Bass

4   Striped bass is a pelagic anadromous species that was introduced to the Delta in 1879. The Delta
5   population is in major decline (Baxter et al. 2008), having collapsed from about 1.5 million fish in
6   2000 to about 500,000 fish in 2007 (California Department of Fish and Game 2012). The striped
7   bass is the most broadly distributed and abundant large piscivorous fish in the Plan Area, although it
8   tends not to use habitats occupied by aquatic vegetation (Nobriga and Feyrer 2007). The diet, both
9   historically (1963–1964, before declines of delta smelt and Chinook salmon) and more recently
10 (2001, 2003) is dominated by mysid shrimp, amphipods, threadfin shad, other striped bass, and
11 infrequently Chinook salmon and smelt (Stevens 1966; Nobriga and Feyrer 2008). Striped bass is a
12 generalist predator that can switch prey depending on predator size and prey availability, often
13 focusing on more abundant or easily captured prey (Nobriga and Feyrer 2008). Striped bass and
14 largemouth bass are known to prey on juvenile Chinook salmon, juvenile steelhead, delta smelt, and
15 Sacramento splittail (Stevens 1966; Moyle 2002; Nobriga and Feyrer 2007, 2008). However, covered
16 species, such as salmon, delta smelt and splittail, have been found to make up only a small
17 proportion of the overall diet of such predators as striped bass (Nobriga and Feyrer 2008).
18 Nevertheless, despite the small percentage of a predator's diet which may be composed of covered
19 fish species, predation may well equate to relatively large losses of covered fish, a point which
20 should not be overlooked.

21 Adult striped bass often congregate near screened diversions, feeding on concentrations of small
22 fish, especially salmon. Striped bass are a major cause of mortality of juvenile salmon and steelhead
23 near the SWP south Delta diversions (Clark et al. 2009).

24 Striped bass spawn in large, nontidal tributaries. Most spawning occurs in the Sacramento River,
25 from above Colusa (about River Kilometer 195) to below the mouth of the Feather River (about
26 River Kilometer 125). Spawning bass may be attracted to large outflows of agricultural return water
27 from Colusa Drain. During wet years, spawning may take place in the Sacramento River portion of
28 the Delta. In the San Joaquin River, successful spawning upstream of the Delta occurs mainly during
29 years of high flow, when the large volume of runoff dilutes salty irrigation wastewater that normally
30 makes up much of the river's flow (Moyle 2002). In years of lower flow, spawning occurs in the
31 Delta itself. Because of interactions among these factors, there are two main spawning areas in the
32 Delta: the Sacramento River from Isleton to Butte City and the San Joaquin River and its sloughs
33 from Venice Island down to Antioch (Moyle 2002). After spawning, striped bass eggs and larvae are
34 transported to the LSZ of the estuary by river currents. Striped bass that are 1 year old and older
35 occur throughout the Bay-Delta and in adjacent freshwater and marine habitats.

5.F.5.1.2.2   Largemouth Bass

37 Largemouth bass are a freshwater nearshore fish that cannot successfully reproduce in brackish
38 water (Nobriga and Feyrer 2007). Largemouth bass were introduced to the Bay-Delta watershed in
39 the late nineteenth century. Largemouth bass prefer warm, shallow waters of moderate clarity and
40 stands of aquatic vegetation. Their numbers have increased recently, associated with expansion of
41 IAV stands and increasing water clarity (Nobriga and Feyrer 2007; Conrad et al. 2010). Adult bass
42 are solitary hunters that may either range widely or remain in a relatively restricted area centered
43 around a submerged rock or branch (Moyle 2002). Nobriga and Feyrer (2007) concluded that

1   largemouth bass may have the highest per capita effect on nearshore fishes, followed by striped bass
2   and then pikeminnow. This estimate is based on the greater frequency and number of native fish in
3   largemouth bass stomachs and their conversion to a fish diet at a small size (Nobriga and Feyrer
4   2007).

5.F.5.1.2.3   Sacramento Pikeminnow

6   The native Sacramento pikeminnow is a freshwater fish, commonly associated with flowing-water
7   habitats (Nobriga and Feyrer 2007). Long-term trends in Sacramento pikeminnow abundance are
8   unknown, but the species is common in the Sacramento River basin (Nobriga and Feyrer 2007). The
9   Sacramento pikeminnow is not a sought-after sport fishery in the Delta. There is, however, a bounty
10   fishery in the upper Sacramento River to reduce predation by these fish on emigrating salmonids
11   (Nobriga and Feyrer 2007). Large pikeminnows typically cruise about in pools during the day in
12   loose groups of five to ten fish, although very large individuals may be solitary. Often by midday they
13   become relatively inactive and return to cover, although some still cruise about, feeding on surface
14   insects or benthos. The largest fish emerge from cover as darkness falls, entering runs and shallow
15   riffles to forage on small fish. Peak feeding usually occurs in the early morning for smaller fish or at
16   night for larger fish. Nighttime predation rates at Red Bluff Diversion Dam apparently were
17   enhanced when lights on the dam made prey more visible (Vogel 2011).

5.F.5.1.3   Predation on Covered Fish Species

19   In the Delta, predation occurs on covered species as larvae (delta smelt, longfin smelt, splittail),
20   juveniles (delta smelt, longfin smelt, salmon, steelhead, splittail, sturgeon) and adults (delta smelt,
21   longfin smelt, splittail, salmonids). Each of these species groups is described below.

22   The rates of encounter between covered fish species and predators in the Delta vary with the
23   different life history patterns. Delta and longfin smelt are mainly pelagic, thus they are most likely to
24   encounter pelagic predators like striped bass.

5.F.5.1.3.1   Chinook Salmon and Steelhead

26   Salmon are likely to encounter striped bass and Sacramento pikeminnow throughout juvenile
27   emigration down the Central Valley rivers and in the Delta. Salmonid juveniles may be vulnerable to
28   largemouth bass while forging in nearshore habitats around areas of SAV. Striped bass and
29   largemouth bass were observed to consume salmonids, but less than 1% of those predators were
30   observed with salmon in their stomachs (Nobriga and Feyrer 2007; Nobriga and Feyrer 2008).
31   Sacramento pikeminnow predation on salmonids has been documented upstream (Vogel et al.
32   1998) but not in the Delta (Nobriga et al. 2006), even though large pikeminnow have been captured
33   in the lower Sacramento River (Nobriga et al. 2006).

34   Salmonids are likely to encounter striped bass and pikeminnow during their juvenile migration from
35   upstream reaches and down through the Bay-Delta. Juvenile salmonids may also encounter
36   largemouth bass while migrating past areas infested with IAV.

5.F.5.1.3.2   Delta Smelt and Longfin Smelt

38   Delta smelt and longfin smelt are largely pelagic. This reduces the likelihood that they will encounter
39   nearshore predators like largemouth bass, but they can overlap with striped bass. In the 1960s,
40   delta smelt were documented in 0 to 2% of striped bass (over 8,000 stomachs examined) (Stevens

1   1966). At that time, delta smelt made up a small proportion (1 to 8% by volume) of the diet in
2   subadults (age 1 and age 2), and trace amounts in young-of-the-year and adult (age 3+) striped bass.
3   In 2001 and 2003 surveys, no delta smelt were found in striped bass stomachs (Nobriga and Feyrer
4   2008).

5   Given their smaller size, delta smelt and longfin smelt are likely vulnerable to a wider range of Delta
6   predators. Smelt spawn in the Delta, and inland silversides may be important predator of smelt eggs
7   and larvae (Bennett 2005). Thus, large fish such as striped bass may not be the most significant
8   predator, and, reductions in such a predator would not reduce direct predation on young smelt life
9   stages. Furthermore, wide-scale reduction in an apex predator could trigger unintended trophic
10   cascades. High uncertainty exists regarding whether the dynamic biotic interaction is top-down
11   control, apparent competition, indirect effects, or other complex interactions (Vander Zanden et al.
12   2006). For example, wide-scale reductions in striped bass could result in competitive release and a
13   compensatory response by silverside or other intraguild competitors.

14   Predator reduction for delta smelt and longfin smelt faces some challenges. First, the probability of
15   benefit may be low, if the program fails to identify the most significant predator species or fails to
16   remove enough predators. Second, unintended negative consequences could result, if too many of
17   the wrong predator or competitor species are reduced. Therefore, the BDCP pilot program will not
18   undertake reduction efforts focused on benefiting delta smelt or longfin smelt.

5.F.5.1.3.3   Sacramento Splittail

20   Splittail are likely to be vulnerable to all three large predators as they are widespread throughout
21   the Delta and also use nearshore habitats to forage. In the Delta, splittail are most abundant in areas
22   of low-density SAV, whereas largemouth bass are most abundant in denser SAV (Brown 2003;
23   Nobriga et al. 2005). One study documented striped bass and largemouth bass consumption of
24   splittail, but splittail were observed in a small fraction (<2%) of the less than 1% of striped bass
25   stomachs and 2% of largemouth bass diets (Nobriga and Feyrer 2007). Splittail are likely vulnerable
26   to striped bass, largemouth bass, and Sacramento pikeminnow because they move widely
27   throughout the Delta, but also use nearshore habitats to forage.

5.F.5.1.3.4   Green Sturgeon and White Sturgeon

29   Green and white sturgeon may experience predation, although the extent to which this occurs
30   within the Delta is unknown. Sturgeon grow very rapidly while in the Delta, allowing them to reach
31   predation "escape size" at a young age. The eggs and early larval stages of green and white sturgeon
32   appear to be the most vulnerable to predation by other fish species, but the magnitude and
33   significance of this predation is not known. It has also been reported that larval and juvenile green
34   sturgeon are subject to predation by both native and introduced fish species. Smallmouth bass
35   (*Micropterus dolomieui*) have been recorded on the Rogue River as preying on juvenile green
36   sturgeon, and prickly sculpin (*Cottus asper*) have been shown to be an effective predator on the
37   larvae of sympatric white sturgeon (Gadomski and Parsley 2005). The rapid growth of juveniles,
38   their relatively large size, and scute development are thought to protect sturgeon older than age 0
39   from all but the largest predators (Beamesderfer and Webb 2002). Predation is not known to be a
40   major factor in the decline of green sturgeon (Adams et al. 2002).

1   ### 5.F.5.1.3.5   Pacific Lamprey and River Lamprey

2   Predation on Pacific lamprey and river lamprey is not well documented within the Delta and the
3   extent to which it occurs is unknown. Lamprey migrate through the Delta at sizes small enough to be
4   consumed by predators and have been found in a striped bass stomach (Nobriga pers. comm.). Egg
5   and larval lamprey life stages appear to be the most vulnerable, although juvenile and possibly even
6   adult life stages are potential prey for a variety of aquatic and terrestrial species. Fish predators of
7   lamprey include channel catfish (*Ictalurus punctatus*), white sturgeon, pikeminnow, sculpins, and
8   logperch (Close et al. 1995). Predation of lamprey within the Delta has not been identified as an
9   issue of concern at this time.

10   ## 5.F.5.1.4   Habitat Structure and Predation "Hotspots"

11   Habitat structure and heterogeneity can affect opportunities for encounter and capture by
12   predators. In open water habitats, striped bass are the most likely primary predator of juvenile and
13   adult delta smelt. Other species, such as largemouth bass, are ambush predators that remain close to
14   cover such as in-water structures or IAV.

15   As described in Section 5.F.4, IAV stands appear to provide habitat that is more favorable to
16   nearshore fishes such as largemouth bass and sunfish that also can take advantage of increased
17   water clarity to find prey (Brown 2003; Nobriga et al. 2005; Nobriga and Feyrer 2007). In IAV-
18   dominated habitats in the Delta, native fishes are very rare and nonnative fishes are dominant
19   (Brown 2003; Feyrer and Healey 2003; Feyrer 2004; Grimaldo et al. 2004; Nobriga et al. 2004;
20   Nobriga et al. 2005). Sunfish have increased in abundance since the 1980s, and the relative
21   abundance of native fish has declined as Brazilian waterweed (*Egeria*) has expanded in the Delta
22   over the past 25 years (Brown and Michniuk 2007). Largemouth bass are strongly associated with
23   dense IAV stands and have increased in abundance and size in the Delta (Nobriga and Feyrer 2007;
24   Conrad et al. 2010). The IAV stands have decreased turbidity, which could enhance prey capture by
25   visual predators (Gregory and Levings 1998). Reduced turbidity may enhance foraging efficiency
26   and reduce cover for delta smelt and other pelagic species (Nobriga et al. 2005). Research in other
27   systems suggests visual predators hunt more successfully in clear water (Gregory and Levings 1998;
28   Gadomski and Parsley 2005). Pelagic fishes, including many smelt species, experience lower
29   predation risks under turbid water conditions (Thetmeyer and Kils 1995; Utne-Palm and Stiansen
30   2002; Horpilla et al. 2004). Some studies have shown decreased foraging rates at increasing
31   turbidities (Sweka and Hartman 2003), while other studies show that increases in turbidity alters
32   foraging activity of predators compensate for the more difficult prey detection, but this does not
33   necessarily reduce feeding rates (Reid et al. 1999). The variability in these findings depends on the
34   predator and prey species studied as well as the range of turbidities evaluated.

35   Habitat features that allow predators to forage more efficiently include structure, dark locations
36   adjacent to light locations, and deep pools that allow them to hide and ambush their prey. Human-
37   made structures (e.g., bank revetment, dams, bridges, water diversions, piers, wharves) can alter
38   local flow patterns and provide habitat features that can both attract predators and disorient small
39   fish such as juvenile salmonids and smelt (Stevens 1966; Decato 1978; Vogel et al. 1988; Garcia
40   1989). An extreme case of concentrated predation is seen at release points for salvaged fish, where
41   large aggregations of piscivorous fish and birds gather to prey on the disoriented fish (Miranda et al.
42   2010). Predatory fish used floating debris trapped against pier pilings as cover and were observed
43   darting out to feed on released salvage fish (Miranda et al. 2010).

1   Several sites throughout the Delta are currently considered hotspots of predator aggregation or
2   activity, as described in Section 5.F.2.5.1, *Reduce Predatory Fish at Hotspots*, and shown in Figure
3   5.F.3-1.

4   Operation of any diversion, including new diversions, can also increase predation. Because of
5   hydraulics around diversion structures, prey fish become disoriented (turbidity, light), and
6   predators tend to aggregate at diversion locations (Kratville 2008). Few direct estimates of
7   predation rates and effectiveness are available. Predation has been evaluated at Red Bluff Diversion
8   Dam and the GCID intakes (Vogel et al. 1988; Vogel 2008). *CM1 Water Facilities and Operation* is
9   expected to create new hotspots at the three north Delta water diversion facilities. Large intake
10   structures have been associated with increased predation by creating predator ambush
11   opportunities and flow fields that disorient juvenile fish (Vogel 2008).

12   Insights about predation can be drawn from studies of entrainment losses at the SWP south Delta
13   facilities. These losses typically are ascribed to predation by striped bass (Figure 5.F.6-1). Losses of
14   tagged hatchery fish are high crossing the CCF. Studies of tagged fish documented losses of 63 to
15   99% of Chinook salmon juveniles and 74% of steelhead between the radial gates to the salvage
16   facility (Clark et al. 2009; Gingras 1997). Mortality associated with collection, handling, transport in
17   trucks, and release is estimated at 2% for Chinook salmon, which are usually juveniles or smolt-
18   sized fish. Estimates of post-release predation are 10 to 30% of the salvaged fish released (National
19   Marine Fisheries Service 2009). A pilot study of marked delta smelt had losses exceeding 90%
20   across the CCF (Castillo et al. in press). Other factors may have contributed to these high losses, such
21   as high water temperatures during summer releases. Another study measured delta smelt mortality
22   associated with collection, handling, transport, and release, ranging 13 to 22% for adults and 42 to
23   63% for juveniles (Morinaka 2010).

24
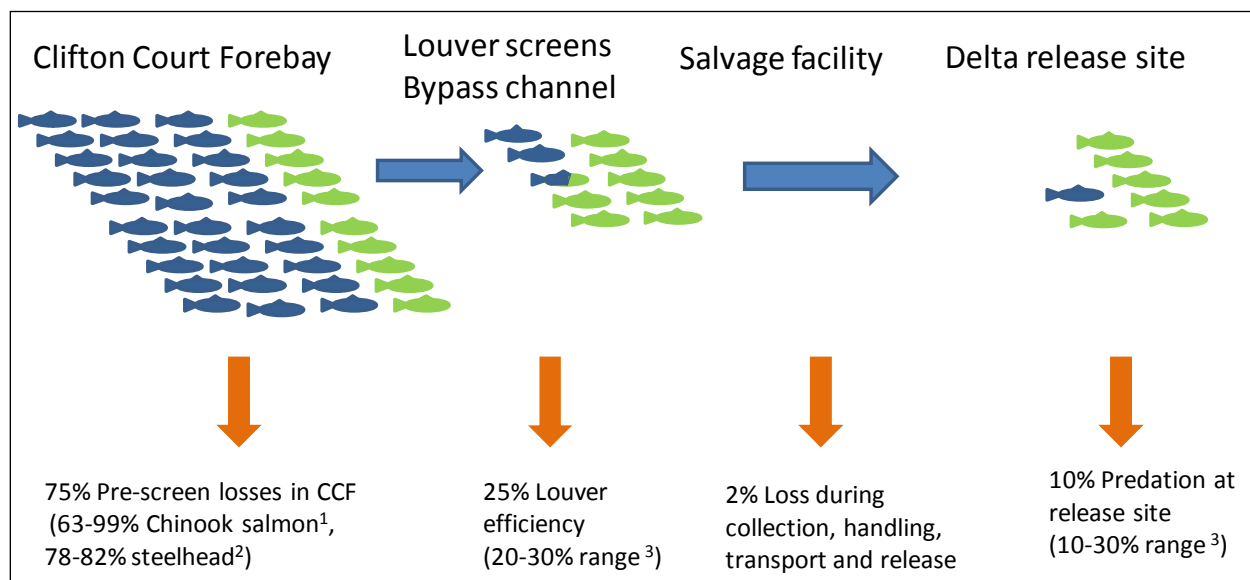
25   Sources: [1] Gingras 1997; [2] Clark et al. 2009; [3] National Marine Fisheries Service 2009.

26   **Figure 5.F.6-1. Predation Losses of Salmon and Steelhead at SWP South Delta Facility, from**
27   **Clifton Court Forebay to Delta Release of Salvaged fish**

1 # 5.F.5.2   Conceptual Models and Hypotheses

2 ## 5.F.5.2.1   Conceptual Models

3 Predator-prey dynamics are influenced by many interacting factors that directly and indirectly
4 influence prey encounter and capture probabilities (Mather 1998; Nobriga and Feyrer 2007; Lindley
5 and Mohr 2003). Factors affecting the opportunity and magnitude of predation include habitat
6 overlap between predator and prey, foraging efficiency by predators, energetic demands of
7 predator, size, life stage, behavior, and relative numbers of predators and prey.

8 Fish tend to be opportunistic foragers that readily switch from one food species to another or
9 concentrate their feeding in areas of greater abundance (Durand 2008). This type of foraging
10 strategy is called Type III functional response to prey availability (*sensu* Holling). The functional
11 response to abundance suggests that fish capitalize on highly abundant organisms and therefore
12 tend not to limit annual recruitment, which makes it difficult to determine the role of piscivorous
13 fish in controlling fish populations (Durand 2008).

14 Habitat structure and species-specific habitat use affect opportunities for predation. As illustrated
15 by Brown (2003) for freshwater tidal wetlands, fish species composition and predator-prey
16 interactions are strikingly different depending on the presence of SAV (Figure 5.F.6-2 and Figure
17 5.F.6-3).

18 The frequency of predation events is determined by three elements: encounter frequency between
19 predator and prey, decisions by predator to attack prey, and capture efficiency of the predator.
20 Encounter frequencies are a function on the relative abundances of predator and prey species, their
21 spatial and temporal overlap, and vulnerability of the prey. Environmental conditions such as
22 reduced river flows and increased water clarity can increase the vulnerability of prey to predation
23 loss. Areas in the Delta considered to have high levels of predator activity are considered predator
24 hotspots. These hotspots are typically areas in which predators have an advantage in successfully
25 capturing prey. For example, structures in the water can create holding habitat for predatory fish,
26 while causing water turbulence, which can temporarily disorient prey fish. In these situations, there
27 can be localized areas of abnormally elevated rates of predation loss for covered fish species.
28 Likewise, areas of the Delta infested with high densities of IAV create ideal habitat for largemouth
29 bass to hold and ambush passing prey. Therefore directly removing predators from a hotspot or
30 eliminating human-made structures that facilitate predation loss could potentially reduce Delta-
31 wide predation of covered fish, thus improving overall survival rates.

1

2
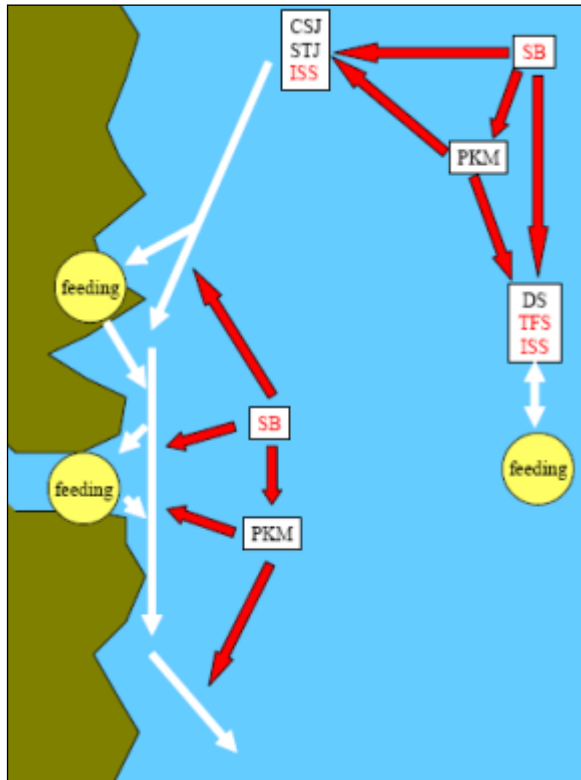
Figure 5.F.6-2. Conceptual Model for Fish Habitat Use in Delta Tidal Wetlands without SAV

5
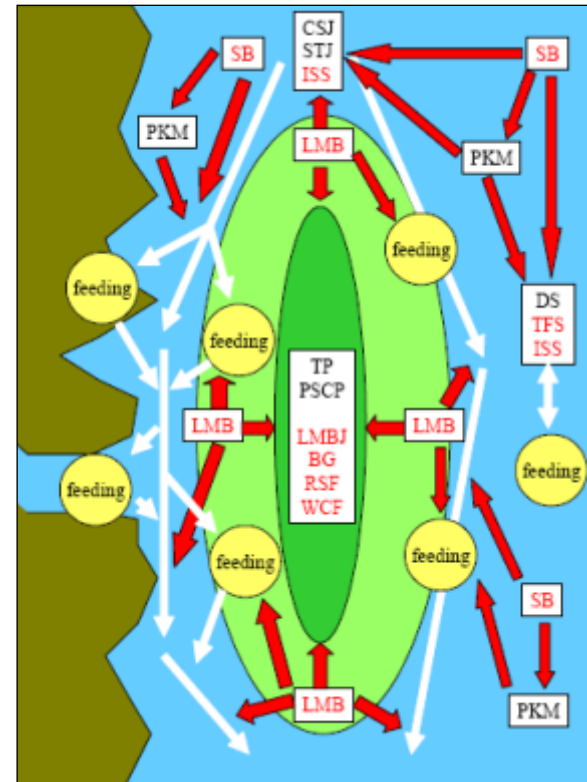
6 **Figure 5.F.6-3. Conceptual Model for Fish Habitat Use in Delta Tidal Wetlands with SAV**

8

9   Note: Species codes in red indicate alien fishes. Red arrows indicate piscivory. White arrows indicate prey movements. Yellow circles represent feeding
10 by prey fishes. Olive green represents emergent vegetation. Light green represents low-density SAV. Dark green represents dense SAV. Species codes:
11 BG-bluegill; CSJ-juvenile Chinook salmon; DS-delta smelt; ISS-inland silverside; LMB-adult largemouth bass; LMBJ-juvenile largemouth bass; PKM-adult
12 Sacramento pikeminnow; PSCP-prickly sculpin; RSF-redear sunfish; SB-adult striped bass; STJ-juvenile splittail; TFS-threadfin shad; TP-tule perch;
13 WCF-white catfish.

14   Source: Brown 2003.

1 Stressors and conservation measures were evaluated for their direct and indirect effects on these
2 three factors (Figure 5.F.6-4).
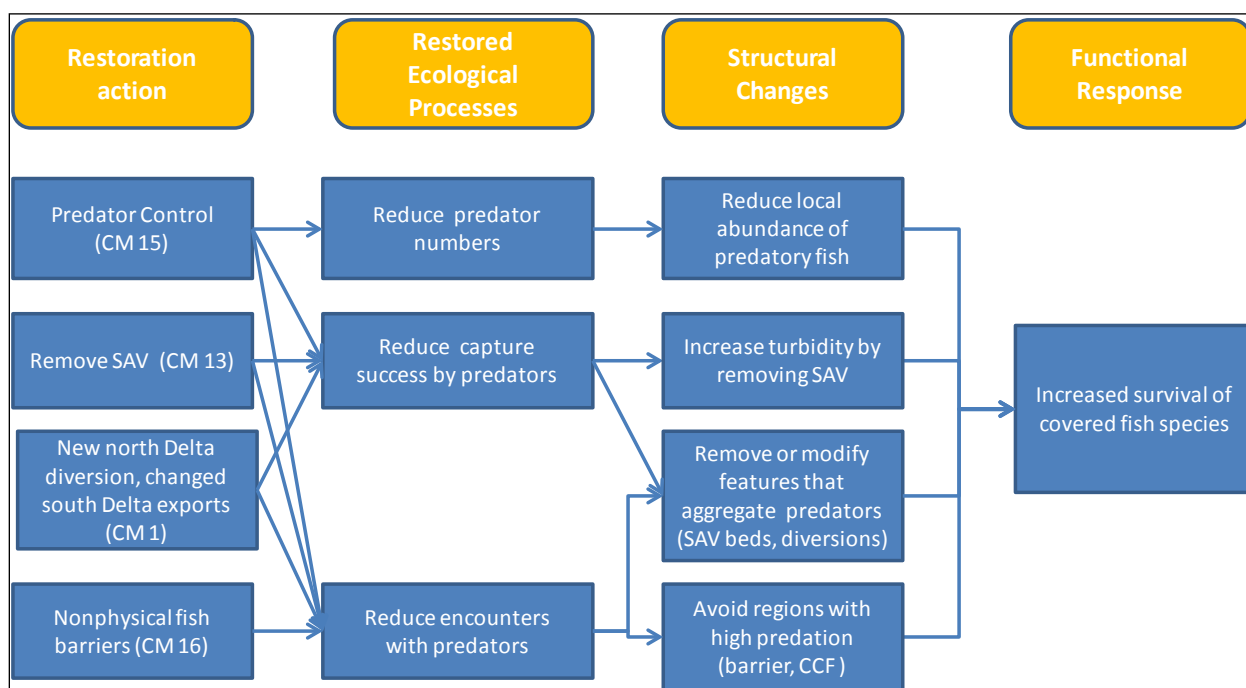
3

4 **Figure 5.F.6-4. Conceptual Model of Predation-Related Effects of BDCP Conservation Measures**

5 ## 5.F.5.2.2   Hypotheses about Predator Reduction

6 Activities that increase the risk of predation on covered fish species in the Delta include:

7 ● Nonnative fish introductions

8 ● Alteration of natural flow patterns

9 ● The proliferation of human-made structures (diversions, abandoned structures, docks or
10   wharfs, etc.)

11 ● Changes in channel characteristics (the formation of deep scour pools) or water quality
12   (turbidity)

13 ● The regular release of salvaged fish at established sites

14 ● Regulations and policies that promote or protect nonnative fish species

15 The effectiveness of conservation measures in reducing predation losses and enhancing survival of
16 covered fishes is evaluated according to the following hypotheses:

17 ● Removing predatory fish at locations with high predator densities or localized high predation
18   (predation hotspots) will locally reduce predation pressure.

19 ● Removing or modifying features that aggregate predators near covered species will reduce
20   encounter rates.

21 ● Removing or modifying features that provide cover for predators will reduce capture success.

1 ● Increasing cover or removing features that reduce cover (e.g., turbidity for smelt) for covered
2 fish species will reduce capture success.

3 ● Reducing predation losses will increase survival and contribute to enhanced populations of
4 covered fishes.

5 More specifically, conducting localized predator reduction at hotspots in the Delta through a variety
6 of control methods should reduce local predator abundance, consequently reducing the localized
7 losses of covered fish species to predation, and increase their survival in the Delta. With the
8 establishment of the pilot program under *CM15 Localized Reduction of Predatory Fishes* and research
9 program, predation-related field experiments and observational studies will be conducted that
10 document the abundance and type of predatory fish present at these sites, along with their relative
11 threat to covered fish species. These studies will help inform fisheries managers whether current
12 hypotheses about the role of predation in the Delta are reasonable representations of ecosystem
13 dynamics in Bay-Delta. Furthermore, findings from these studies will help guide an adaptive
14 management process by the Implementation Office, helping resource managers determine whether
15 full-scale localized predator reduction actions can feasibly reduce predation-related loss of covered
16 fish species and improve their survival through the Delta.

17 # 5.F.5.3   Potential Effects: Benefits and Risks

18 ## 5.F.5.3.1   Chinook Salmon and Steelhead

19 ### 5.F.5.3.1.1   CM1 Water Facilities and Operation

20 Juvenile Chinook salmon and steelhead are exposed to predation as they migrate downstream and
21 through the Delta. Juvenile steelhead are relatively less vulnerable because they migrate as older,
22 larger fish than Chinook salmon juveniles. Predation risk can be higher at water diversion facilities,
23 especially at CCF. Under existing biological conditions, exports at the south Delta facilities can alter
24 flow patterns in the Delta, which can alter the migration pathway of juvenile Chinook salmon and
25 steelhead toward the central and south Delta (details in Appendix 5.C, *Flow, Passage, Salinity, and*
26 *Turbidity*) and increase entrainment at the south Delta facilities (details in Appendix 5.B,
27 *Entrainment*).

28 Implementation of CM1 includes (1) installation and operation of new north Delta water diversion
29 facilities with state-of-the-art fish screens, and (2) reduced pumping at the existing south Delta
30 facilities.

31 The effects of each component on localized predation are analyzed separately below.

32 **North Delta Diversions**

33 The physical characteristics of structures such as water intakes can increase encounter rates and
34 prey capture success by predators. Instream structures create areas of turbulence and lower
35 velocity refuge habitat that attract predatory fish or that concentrate or disorient juvenile salmonids
36 (Vogel 1995, 2011). The new north Delta intake structures will be three separate intake structures
37 located along the shore on the mainstem Sacramento River between Clarksburg and Courtland.
38 Relative to other intake design alternatives, the proposed on-shore diversions have minimal
39 structures in the main flow of the river. This will reduce instream structure and areas where

1   predators can aggregate at or near the diversions and should reduce the risk of predation to covered
2   fish species, especially juvenile salmonids.

3   Potential predation losses are estimated using two methods: bioenergetics modeling and estimates
4   based on a presumed 5% loss per intake.

5   ***Bioenergetics Modeling***

6   The bioenergetics model estimated consumption of juvenile salmon and steelhead by striped bass
7   (Table 5.F.6-1, Table 5.F.6-2, Table 5.F.6-3, and Table 5.F.6-4). A median value for striped bass
8   density results in an estimated 119 predators per 1,000 feet of intake (672 fish total for the three
9   intakes). Comparing consumption losses with the outmigrating Chinook salmon population that
10   reaches the Delta, the estimated losses represent less than 0.7% of the outmigrating juvenile
11   population (Table 5.F.6-2 and Table 5.F.6-4). Increased water temperatures (in warmer months or
12   due to long-term climate change) are associated with higher metabolism of striped bass predators
13   and thus increased consumption. However, model predictions of striped bass predation rates barely
14   increase (0.0 to 0.02% of annual production) for the late long-term scenarios. By run, the estimated
15   loss represents 0.28 to 0.30% of the juvenile fall-run Chinook salmon population, 0.22 to 0.23% of
16   the spring-run population, 0.19% of the winter-run Chinook salmon population, and 0.67 to 0.69%
17   of the late fall–run Chinook salmon population (Table 5.F.6-2 and Table 5.F.6-4).

18   **Table 5.F.6-1. Annual Total of Juvenile Chinook Salmon (Number) Consumed by Striped Bass at North**
19   **Delta Intakes in Early Long-Term with No Localized Predator Reduction**

Striped Bass per 1,000 Feet of Intake	Total Striped Bass	Number of Spring-Run Chinook Salmon	Number of Fall-Run Chinook Salmon	Number of Winter-Run Chinook Salmon	Number of Late Fall–Run Chinook Salmon
18 (Low)	102	1,400	25,900	700	4,300
119 (Median)	672	9,300	171,000	4,900	28,600
219 (High)	1,237	17,200	314,700	9,000	52,700

20

21   **Table 5.F.6-2. Percentage of Total Juvenile Chinook Salmon Consumed by Striped Bass in Early Long-**
22   **Term with No Localized Predator Reduction**

Striped Bass per 1,000 Feet of Intake	Total Striped Bass	Spring-Run Chinook Salmon (%)	Fall-Run Chinook Salmon (%)	Winter-Run Chinook Salmon (%)	Late Fall–Run Chinook Salmon (%)
18 (Low)	102	0.03	0.04	0.03	0.10
119 (Median)	672	0.22	0.28	0.19	0.67
219 (High)	1,237	0.41	0.51	0.35	1.23

23

1   **Table 5.F.6-3. Annual Total of Juvenile Chinook Salmon Consumed by Striped Bass at North Delta**
2   **Intakes in Late Long-Term with No Localized Predator Reduction**

Striped Bass per 1,000 Feet of Intake	Total Striped Bass	Number of Spring-Run Chinook Salmon	Number of Fall-Run Chinook Salmon	Number of Winter-Run Chinook Salmon	Number of Late Fall–Run Chinook Salmon
18 (Low)	102	1,500	27,500	800	4,400
119 (Median)	672	9,600	181,600	5,000	29,300
219 (High)	1,237	17,700	334,300	9,200	54,000

3

4   **Table 5.F.6-4. Percentage of Total Juvenile Chinook Salmon Consumed by Striped Bass in Late Long-**
5   **Term with No Localized Predator Reduction**

Striped Bass per 1,000 Feet of Intake	Total Striped Bass	Spring-Run Chinook Salmon (%)	Fall-Run Chinook Salmon (%)	Winter-Run Chinook Salmon (%)	Late Fall–Run Chinook Salmon (%)
18 (Low)	102	0.03	0.04	0.03	0.10
119 (Median)	672	0.23	0.29	0.19	0.68
219 (High)	1,237	0.42	0.54	0.35	1.26

6

7   Implementing a predator reduction program at the north Delta diversions would reduce localized
8   losses somewhat, as discussed further in Section 5.F.5.1.3.4, *Green Sturgeon and White Sturgeon*.

9   As with all piscivorous fishes that swallow their prey whole, striped bass become more efficient as
10 they grow larger because they gain a size advantage over individual prey, which are generally
11 smaller (e.g., juvenile salmon). The rate of predation by striped bass on a particular prey item is
12 assumed to be proportional to the frequency of encounters with that prey type (Type III functional
13 response). Therefore, it is estimated that many more fall-run Chinook salmon are consumed than
14 winter-run or spring-run juveniles because they are generally more abundant. However, because
15 salmon in the Delta are relatively rare, the functional response of striped bass to changing prey
16 densities actually was based on data of threadfin shad.

17 ***Fixed Predation Loss***

18 Based on DPM analysis of survival by Chinook salmon smolts emigrating from the Sacramento River
19 Basin (Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*), under the ESO, a proportion of smolts
20 reaching the Delta would emigrate through the Yolo Bypass and downstream to Rio Vista, thus
21 bypassing the north Delta intakes entirely. The average proportion of Chinook salmon smolts
22 modeled entering the Yolo Bypass was 12% for winter-run (range 2–32%), 9% for spring-run
23 (range 2–24%), and 4% for fall-run and late fall-run (range 1–12%) (Table 5.F.6-5). The remainder
24 of smolts would outmigrate via the mainstem Sacramento River past the proposed north Delta
25 intakes: 88% of winter-run salmon smolts, 91% of spring-run salmon smolts, 96% of Sacramento
26 River basin fall-run salmon smolts, and 96% of late fall-run salmon smolts.

27 Under the fixed predation loss method, it is assumed that juvenile salmon passing the proposed
28 north Delta screened intakes would be subject to a loss rate of 5% per intake, due to various screen-
29 related effects associated with impingement, predation, and exhaustion. The 5% loss term is based
30 on GCID observations as described above. The cumulative attrition across the three intakes of the

1 entire north Delta diversion complex based on the fixed 5%-per-screen assumption is an annual
2 average of 11.7% of winter-run smolts, 12.1% of spring-run smolts, and 12.8% of fall-run and late
3 fall-run Chinook salmon smolts.

4 This approach likely overestimates the mortality rates associated with the north Delta facilities. Not
5 all salmon migrating down the lower Sacramento River would swim in close enough proximity to
6 the on-bank diversion intakes to be directly or indirectly affected by their presence. Also, the north
7 Delta intake screen and diversion design and siting are much different from the GCID structure on
8 which this 5% loss assumption is based. In addition, the 5% loss term applied for each of the north
9 Delta diversion intakes does not take into account the normal baseline mortality that occurs in that
10 reach of the Sacramento River. Results from the DPM analysis indicate that baseline survival of
11 Chinook salmon smolts through that reach averages around 67–76% (depending on run). Therefore,
12 because the 5% loss term presumes a 5% proportional reduction in outmigration survival per
13 diversion, the absolute percent reduction in reach-specific survival would be smaller than 5% per
14 intake. Finally, localized predator reduction could have at least a small beneficial effect.

15 **Table 5.F.6-5. Average Proportion of Chinook Salmon Smolts Reaching the North Delta that Enter**
16 **Yolo Bypass or Survive to the North Delta Diversion Reach, and the Average Proportion Smolts**
17 **Lost at the North Delta Intakes**

	ESO_ELT			ESO_LLT		
Race	% Enter Yolo Bypass[1]	% Survival to NDD[2]	% Loss at NDD Complex[3]	% Enter Yolo Bypass[1]	% Survival to NDD[2]	% Loss at NDD Complex[3]
Winter-run	12%	93.07%	11.69%	12%	93.07%	11.67%
Spring-run	9%	93.12%	12.10%	9%	93.12%	12.09%
Fall-run	4%	93.17%	12.80%	4%	93.17%	12.82%
Late fall–run	4%	93.08%	12.80%	4%	93.08%	12.81%

Notes:
[1] Proportion of emigrating Sacramento River Basin smolt population entering Yolo Bypass.
[2] Proportion of migrating smolts surviving to north Delta intakes (survival between Fremont Weir to north Delta Intake reach) estimated by the Delta Passage Model (DPM).
[3] Proportion lost at the north Delta intakes based on NMFS assumption of 5% loss per intake (3 intakes total) for the group that passes the north Delta diversion complex.

18

19 **South Delta Diversion Facilities**

20 Reduction in the volumes and rate of water exported from the south Delta SWP and CVP export
21 facilities will contribute directly to a reduction in the numbers of juvenile salmon and steelhead that
22 would be at risk of entrainment and salvage. Expected outcomes based on reduced entrainment for
23 the evaluated starting proposal compared with baseline conditions are described further in
24 Appendix 5.B, *Entrainment.* Reduced pumping at the existing south Delta facilities is expected to
25 result in the reduced entrainment and consequently reduced predation of covered fish species at the
26 facilities.

27 Incremental losses of fish vary at different steps along the SWP and SVP screening process (Table
28 5.F.6-6). The greatest losses are pre-screen losses in the CCF (75%, range 63–99%) and louver
29 efficiency at the CVP Tracy fish Collection Facility (53% loss). Pre-screen entrainment loss at the CCF
30 is the greatest effect (Gingras 1997; Clark et al. 2009; National Marine Fisheries Service 2009).

1   Predation losses in the forebay have been estimated at 63–99% for salmon (Gingras 1997) and 74–
2   86% for steelhead (Clark et al. 2009), based on studies of tagged hatchery fish.

3   Modifying post-salvage release activities, such as regularly changing release sites and timing, will
4   benefit covered species that are successfully salvaged and survive transport, but those losses
5   represent only a small fraction of the overall losses.

6   **Table 5.F.6-6. Overall Survival of Fish Entrained by the Export Pumping Facilities at the Tracy Fish**
7   **Collection Facility and the John E. Skinner Fish Protective Facility**

Estimate of Survival for Screening Process at the SWP and CVP[1]				
	SWP		CVP[2]	
	Percent Survival	Running Percent	Percent Survival	Running Percent
Pre-screen survival	25% [3,4] (75% loss)	25%	85%[5] (15% loss)	85%
Louver efficiency	75% (25% loss)	18.75%	46.8%[6] (53.2% loss)	39.78%
Collection, handling, transport, and release survival	98% (2% loss)	18.375%	98% (2% loss)	38.98%
Post release survival (predation only) [7]	90% (10% loss)	16.54%	90% (10% loss)	35.08%

Source: National Marine Fisheries Service 2009 (Biological Opinion).
Notes:
[1] These survival rates are those associated with the direct loss of fish at the state and federal fish salvage facilities. Please see the text for a more thorough description.
[2] These values do not incorporate the 45% of the operational time that the louvers are in noncompliance with the screening criteria. The actual values of the louver efficiency during this time are not available to NMFS. These values would determine the percentage of survival through the facility under real time circumstances.
[3] Prescreen loss for the SWP is considered to be those fish that enter Clifton Court Forebay that are lost to predation or other sources between entering the gates and reaching the primary louvers at the Skinner Fish Protection Facility.
[4] Estimates have ranged from 63 to 99% (Gingras 1997). Recent steelhead studies indicate a loss rate of approximately 78 to 82% (Clark et al. 2009).
[5] Prescreen survival in front of the trash racks and primary louvers at the Tracy Fish Control Facility (TFCF) have not been verified, but are assumed to be 15%.
[6] Overall efficiencies of the louver arrays at the TFCF have been shown to be 46.8% (59.3% primary, 80% secondary). Recent studies indicate overall efficiencies during low-flow periods could be less than 35% (Bureau of Reclamation 2008). This value does not include periods when the louvers are being cleaned, where overall efficiency drops toward zero.
[7] Predation following release of salvage fish ranges from less than 10% to 30% according to NMFS (2009). NMFS uses the lower estimate to give a conservative estimate of loss. Actual loss may be greater, particularly in the winter when the density of salvage fish released is low, and predators can consume a greater fraction of the released fish (Clark et al. 2009).

8

9   The reduction in predation loss attributable to reduced pumping under the conservation strategy
10   can be estimated from the decrease in salvage compared to existing conditions. Estimates of total
11   salvage were taken directly from Appendix 5.B, *Entrainment*. Assuming that predation is 75% at the
12   SWP and 15% at the CVP facilities, predation losses are decreased by several thousand for steelhead
13   and each race of Chinook salmon under CM1 in both the early and late long-term scenarios (Table
14   5.F.6-7). This decrease in predation loss was further compared with annual estimates of juvenile
15   salmon population by race: 2.6 million winter-run juveniles; 3.2 million spring-run juveniles, and

1 55.2 million fall-/late fall–run juveniles. The population level of juvenile steelhead in the Central
2 Valley is unknown at this point. Estimated predation losses at the south Delta facilities were
3 decreased substantially under the ESO in comparison with existing biological conditions for
4 steelhead (55–58%) and fall-/late fall–run Chinook salmon (56–60%), and spring-run Chinook
5 salmon (14–24%), but little changed for winter-run (–3% to 8%). In the context of the population
6 for each race, however, these differences make up no more than 0.1% of estimated annual
7 production for Chinook salmon (Table 5.F.6-8).

8 **Table 5.F.6-7. Pre-Screen Losses of Salmonids at SWP and CVP South Delta Facilities**

Species/Race	Existing Conditions ELT (EBC2_ELT)	Existing Conditions LLT (EBC2_LLT)	ESO_ELT	ESO_LLT
Steelhead	7,040	6,765	3,154	2,827
Fall-/late fall–run	4,711	4,564	2,080	1,815
Winter-run	20,321	20,474	20,879	18,770
Spring-run	30,678	29,944	26,389	22,839
Note: Based on assumption of 75% predation loss of salmonids in SWP and 15% predation loss in CVP.				

9

10 **Table 5.F.6-8. Reduction (Number and Percent) in Pre-Screen Losses of Salmonids at SWP and CVP**
11 **South Delta Facilities under Existing Conditions and Evaluated Starting Operations**

Species/Race	Existing Conditions vs. ESO_ELT	Existing Conditions vs. ESO_LLT	% of Total Population (ELT)	% of Total Population (LLT)
Steelhead	3,886 (55%)	3,939 (58%)	Unknown	Unknown
Fall-/late fall–run	4,630 (56%)	7,475 (60%)	<0.1%	<0.1%
Winter-run	2,630 (-3%)	2,749 (8%)	0.1%	0.1%
Spring-run	1,585 (14%)	1,704 (24%)	<0.1%	<0.1%
Note: Based on assumption of 75% predation loss of salmonids in SWP and 15% predation loss in CVP.				

12

13 5.F.5.3.1.2 Habitat Restoration

14 Restored aquatic habitats are expected to support juvenile salmonids that migrate through or rear in
15 the Delta by providing foraging habitat and cover. However, these habitats also may be used by
16 predatory fish. The potential effects of the different types of aquatic habitat restoration are
17 discussed qualitatively below. In general, predation risk for juvenile steelhead is expected to be
18 lower than that for juvenile Chinook salmon because of their greater size and better swimming
19 performance.

20 **CM2 Yolo Bypass Fisheries Enhancement**

21 CM2 is intended to improve passage at the Fremont Weir and increase Yolo Bypass inundation and
22 thereby reduce predation risk for migrating juvenile steelhead and Chinook salmon by providing a
23 migration route with lower predation and entrainment risk (avoiding the north and south Delta
24 diversions). Mortality, which occurs along the primary migratory routes for juvenile salmonids, is
25 hypothesized to be the largest factor influencing Delta emigration success. Although concerns have
26 been raised about stranding on the floodplain, juvenile Chinook salmon do not appear to be prone to
27 stranding mortality (Sommer et al. 2005). The Yolo Bypass drains fairly efficiently, leaving little

1   isolated area where stranding can occur. The exception is at water control structures, namely the
2   concrete weir ponds at the Fremont and Sacramento Weirs.

3   There may be a potential for predators also to benefit from the Yolo Bypass restoration measures,
4   but that risk likely is outweighed by the benefits to salmonids from the restoration measures.
5   Sommer and coauthors (2001) examined the survival issue during 1998 and 1999 studies by
6   conducting paired releases of tagged juvenile salmon into the Yolo Bypass and the Sacramento
7   River. They found that the Yolo Bypass release groups had somewhat higher survival indices than
8   the Sacramento River. Feyrer and coauthors (2006) analyzed seasonally inundated floodplain
9   habitat in the Yolo Bypass and found a much higher presence of juvenile salmon than predators like
10 largemouth bass and striped bass, suggesting that Yolo Bypass restoration efforts likely will benefit
11 salmon and steelhead more than nonnative fish predators. Therefore, even with stranding and
12 predation losses in some places or some years, these risks may be offset by increased rearing habitat
13 and food resources for covered fish species in other years (Sommer et al. 2001, 2005; Brown 2002).
14 The effect of increasing flows to the Yolo Bypass would provide foodweb and migration benefits that
15 would outweigh mortality risks from stranding or predation loss, but the impact on the overall
16 Chinook salmon population would be small to moderate because on average fewer than 10% of the
17 juvenile salmonid population would enter the Yolo Bypass under the Plan, based on current
18 modeling.

19 **CM4 Tidal Natural Communities Restoration**

20 Restored tidal wetlands are expected to increase food supply, benefitting rearing juvenile salmonids.
21 Increased tidal habitats, especially along juvenile salmonid migration corridors, also might improve
22 survival by providing refuge from predation. If restored subtidal areas are invaded by IAV, however,
23 this could increase abundance of largemouth bass and hence incur some predation losses of those
24 juveniles exploiting the restored tidal habitat. However, Chinook salmon are most abundant when
25 water temperatures are relatively low and largemouth bass metabolic and feeding rates are also low
26 (Brown 2003) suggesting that the risks may be outweighed by the benefits from tidal habitat
27 restoration. The effect of tidal habitat restoration would provide a benefit for juvenile salmonids by
28 increasing food production and cover. The risk of IAV establishment attracting largemouth bass
29 would be minimized by implementation of *CM13 Invasive Aquatic Vegetation Control* to suppress and
30 prevent IAV establishment in the restored areas.

31 **CM5 Seasonally Inundated Floodplain Restoration**

32 Benefits and risks for Chinook salmon and steelhead in restored seasonally inundated floodplains in
33 the Delta are expected to be similar to those observed in the Yolo Bypass. Seasonal floodplain
34 restoration should be beneficial to juvenile salmonids by providing additional rearing habitat.
35 Sommer and coauthors (2001) observed higher growth rates of juvenile salmon reared in the Yolo
36 Bypass floodplains compared to salmon that remained the Sacramento River channel. Inundated
37 floodplains provide a higher abundance of prey for juvenile salmon, leading to faster growth. As
38 juvenile salmon become larger, survivorship increases, in part because of lower risk of predation. A
39 5-year study of fish abundance in restored floodplain habitat in the Cosumnes River found high
40 abundance of centrarchids such as bluegill and largemouth bass in adjacent permanent sloughs
41 (Moyle et al. 2007). These piscivorous predators typically spawn in main channel habitats, although
42 juvenile centrarchids quickly moved into these seasonal floodplains as opportunistic feeders and
43 adults occasionally spawned in temporary floodplain ponds. The restored Cosumnes River
44 floodplain is inundated in winter and early spring, when juvenile Chinook salmon can use it, but

1   drains by late spring before many nonnative warmwater species spawn (Moyle et al. 2007). Feyrer
2   and coauthors (2006) observed much higher presence of salmon than predators in restored
3   floodplains, which supports the concept that more restored floodplains in the Delta likely will
4   provide a net benefit for salmonids.

CM6 Channel Margin Enhancement

6   Cover is an important habitat component for juvenile salmonids as they migrate through the lower
7   Sacramento and San Joaquin Rivers and the Delta, serving in part as a means to avoid predators.
8   Channelized, leveed, and riprapped banks common in the lower river reaches and sloughs of the
9   Delta region offer little protection for covered fish species from either fish or avian predators.

10 Enhancing channel margins may contribute to a net improvement in survival if the recovered
11 habitats contribute to increasing prey resource availability locally and regionally, improving
12 migration habitat connectivity, and providing other benefits to migratory native fish while reducing
13 habitat benefits for nonnative predators. Juvenile Chinook salmon and steelhead are expected to
14 inhabit restored channel margin habitat and seasonal wetlands located along the Sacramento River
15 as resting and foraging areas during their migration downstream. Cobbles and boulders on the
16 banks can provide flow breaks that provide shelter and feeding stations for juveniles. Natural bank
17 areas also have lower predator densities compared to riprapped channel margins (Michney and
18 Hampton 1984; Cavallo et al. 2004).

19 Restoring natural river or slough channel banks is expected to benefit covered fish species by
20 eliminating channel bank features (e.g., riprap) attractive to fish predators. However, a quantitative
21 assessment is difficult because data is lacking on predator densities associated with enhanced
22 channel margin. Increased food availability resulting from habitat expansion is considered to be a
23 benefit to juvenile salmon and steelhead, although the risk of predation may contribute to increased
24 juvenile mortality. Shallow-water habitats also may provide a refuge from predation by larger
25 pelagic fish such as striped bass, but also may harbor black bass if these areas become colonized
26 with IAV (Nobriga and Feyrer 2007).

CM7 Riparian Natural Community Habitat

28 Riparian restoration could provide additional cover for both covered species and predators,
29 depending on whether riparian vegetation is located at the land-water interface, where it could
30 provide underwater structure (e.g., undercut banks, roots, woody debris) or direct shading.
31 Increased inputs of woody debris and shading from riparian restoration would benefit particularly
32 outmigrating juvenile salmonids by providing more areas of shallow-water refuge from predators.
33 Larval delta smelt rearing in littoral areas also may benefit from the increase in nearshore cover.

5.F.5.3.1.3   CM13 Invasive Aquatic Vegetation Control

35 Control of IAV would reduce habitat that supports predatory fish in freshwater nearshore habitat.
36 Largemouth bass, a very effective nearshore predator, recently has shown an increase in abundance
37 and size in the Delta and is strongly associated with dense IAV stands (Nobriga and Feyrer 2007;
38 Conrad et al. 2010). A decrease in IAV in the Delta should open up nearshore habitats used by
39 juvenile salmonids for cover and rearing while reducing their encounters with piscivorous
40 predators like largemouth bass. Dense IAV cover also has been associated with reduction of water
41 turbidity in the Delta (Brown and Michniuk 2007). Removal of IAV may provide increased turbidity,

1   which is associated with reduced hunting success of visual predators like largemouth bass and
2   striped bass (Gregory and Levings 1998).

3   There is some potential that largemouth bass may move from areas of IAV removal and congregate
4   even more densely in untreated areas, concentrating predation pressure on covered fish species in
5   the remaining IAV areas. Juvenile salmonids may also be present along the edges of IAV mats,
6   utilizing them for cover from overhead predators and open water predators such as striped bass.
7   Therefore, the removal of IAV could be detrimental to migrating juvenile salmonids, at least in the
8   short term, as the effects of IAV removal on predation level could increase until a new equilibrium is
9   reached (National Marine Fisheries Service 2007). This increase in predation level is likely due
10 primarily to increased encounter levels since cover for prey fish species has been eliminated.

5.F.5.3.1.4   CM15 Localized Reduction of Predatory Fishes

12 This action is expected to benefit covered fish species by reducing predation mortality at hotspots
13 throughout the Delta. Targeted predator removal focused at identified hotspots in the Delta is
14 expected to locally reduce predator numbers and increase survival of juvenile salmonids migrating
15 through the Delta as well as delta smelt and longfin smelt. Removing or eliminating structural or
16 hydraulic elements that attract and/or provide cover for predatory fish will reduce concentrations
17 and predation effectiveness. Removing predators from release sites, modifying fish salvage
18 activities, and reduced pumping at the existing CVP and SWP diversion facilities in the south Delta
19 also are expected to benefit covered species.

20 The latest quantitative information that relates to striped bass predation on salmon is based on a
21 predator diet study by Nobriga and Feyrer (2007). From this study, it is estimated that striped bass
22 consume an average 0.01 juvenile salmon per day. Based on an average salmonid migration period
23 of 150 days, it is possible to calculate a rough estimate for the effectiveness of a predator removal
24 program. There is a high level of uncertainty associated with this type of analysis, but these
25 estimates provide a basis for characterizing the general magnitude of the reduction of salmon loss to
26 striped bass predation due to localized removal efforts.

27 *CM15 Localized Reduction of Predatory Fishes* would initially implement a pilot program and
28 research program, which would in part help find the balance between implementing a sufficient
29 level of removal effort versus the logistical constraints of an ongoing removal program (e.g.
30 availability of trained workers; program budget; availability of boats and equipment). The following
31 are assumptions on the potential level of effort for a hypothetical predator reduction program, with
32 removal effort estimates to be refined in the future based on findings from the CM15 pilot program
33 and research program.

34 ● Biweekly (twice per week) predator removal at the three proposed north Delta intakes during
35   the October through June period removes 2,220 (10 fish per day * 2 days per week * 37 weeks *
36   3 sites = 2,200) striped bass from the system.

37 ● Biweekly (twice per week) predator removal at head of Old River during the October through
38   June period removes 740 (10 fish per day * 2 days per week * 37 weeks = 740) striped bass from
39   the system.

40 ● Biweekly (twice per week) predator removal at three sites in Georgiana Slough during the
41   October through June period removes 2,200 (10 fish per day * 2 days per week * 37 weeks *
42   3 sites = 2,220) striped bass from the system.

1 ● Biweekly (twice per week) predator removal at Paintersville Bridge during the October through
2   June period removes 740 (10 fish per day * 2 days per week * 37 weeks = 740) striped bass from
3   the system.

4 ● Weekly predator removal at each of the eight CVP/SWP salvaged fish release sites during the
5   October through June period removes 2,960 (10 fish per day * 1 day per week * 37 weeks *
6   8 sites = 2,960) striped bass from the system.

7 Given these assumptions listed above, a predator removal program at all the above sites would
8 collectively remove roughly 8,880 Age-1 and older striped bass from the system annually. The
9 feasibility of sustaining this presumed level of removal effort is unknown. Based on an average
10 striped bass consumption rate of 0.01 juvenile salmon per day and an average juvenile salmon
11 exposure (migration) period of 150 days, the predator removal program theoretically would reduce
12 the number of juvenile salmon lost to striped bass predation during the first year of full
13 implementation by approximately 13,320 fish (8,880 predators * 0.01 juvenile salmon consumed
14 per day * 150 days average juvenile salmon migration period = 13,320 juvenile salmon). Note that
15 the above rough estimate does not take into account predation of salmonids by other predators
16 besides striped bass, recolonization of hotspots by the highly mobile striped bass, or size of the
17 removed striped bass.

18 Using the bioenergetics modeling data, one could also estimate effects for just the north Delta
19 intakes by assuming a certain efficiency in predator reduction efforts. Removing 101 striped bass
20 (15% of the median predator density of 119 bass per 1,000 feet, or 672 bass before treatment) from
21 the three north Delta intakes would result in a concomitant 15% reduction in total annual
22 consumption of juvenile Chinook salmon (Table 5.F.6-9). By run, the estimated loss with predator
23 reduction represents 0.25% of the juvenile fall-run Chinook salmon population, 0.19% of the spring-
24 run population, 0.16% of the winter-run Chinook salmon population, and 0.58% of the late fall–run
25 Chinook salmon population. Compared to losses without predator removal (Table 5.F.6-4), this
26 represents a very minor increase relative to total annual production, ranging from 0.03% more
27 juveniles for winter-run Chinook salmon to 0.11% more juveniles for late fall–run Chinook salmon.
28 This may be a conservative estimate of predator removal benefits, if targeted removal (e.g.,
29 electrofishing) is more effective at removing larger predators (which have higher consumption rates
30 and capture efficiency) than the smaller, younger predators.

31 **Table 5.F.6-9. Annual Total (Percentage) of Juvenile Chinook Salmon Consumed by Striped Bass at**
32 **North Delta Intakes in Late Long-Term with 15% Predator Reduction**

Striped Bass per 1,000 Feet of Intake	Total Striped Bass after 15% Removal	Spring-Run Chinook Salmon	Fall-Run Chinook Salmon	Winter-Run Chinook Salmon	Late Fall–Run Chinook Salmon
18 (low)	87	1,275 (0.03%)	23,375 (0.04%)	680 (0.03%)	3,740 (0.09%)
119 (median)	571	8,160 (0.19%)	154,360 (0.25%)	4,250 (0.16%)	24,905 (0.58%)
219 (high)	1,051	15,045 (0.36%)	284,155 (0.46%)	7,820 (0.30%)	45,900 (1.07%)

33

34 Predator removal treatments would likely have only have a short-term effect, as the Delta is an open
35 aquatic system and recolonization of treated areas by new fish predators may be rapid. However,
36 removal actions could be timed during peak migration periods to more effectively reduce predation
37 at the north Delta diversions.

1   Results of a recent study by Cavallo and coauthors (2012) suggest that intensive, site-specific
2   predator reduction could be an effective management strategy to enhance salmon survival through
3   the Delta. However, benefits may be short-term and the effectiveness of repeated treatment
4   remained unclear. Cavallo and coauthors (2012) applied the hypothesis that predator reductions
5   and flow pulses would increase survival of emigrating juvenile Chinook salmon in the North Fork
6   Mokelumne River. Applying a "before-after-control-impact" study design, they acoustically tagged
7   juvenile fall-run Chinook salmon and removed predators from an "impact" reach of the river.
8   Researchers conducted two separate predator removal treatments, set 1 week apart, by boat
9   electrofishing on a 1.6 km reach of river. For each treatment, paired releases of tagged juvenile
10 salmon were made 1 and 2 days following the predator removal, one release into the experimental
11 reach and the other release concurrently into the control reach. The researchers estimate a predator
12 removal efficiency (of the fish predators vulnerable to electrofishing) of 91% (144 of 158) in the
13 first removal treatment and 83% (497 of 601) in the second removal, with each removal treatment
14 taking 1 day.

15 This study provides valuable insight into how many predators realistically can be removed per day;
16 however, the size and species composition of the removed predators are unknown. After targeted
17 predator removal in the impact reach, researchers released paired groups of tagged juvenile salmon
18 into impact and control reaches in consecutive days immediately following predator removal, and
19 recaptured the tagged juveniles downstream. Despite generally encouraging results after the initial
20 predator removal treatment in which there was 100% survival of juveniles, the researchers
21 observed that there was no difference in survival after the second predator removal treatment
22 compared to no predator removal (approximately 70 to 80% survival). Presumably, the apparent
23 benefit from initial predator removal might be undone through an influx of new predators to the
24 treatment site. Sustained effort over time may be necessary to benefit juvenile salmon survival.

25 Risks associated with localized predator removal programs include the potential bycatch of
26 steelhead or Chinook salmon during beach seining, gill netting, angling, electrofishing, and other
27 capture methods. Adult salmonids caught in nets (fyke, beach seine, or gill nets) could suffer
28 abrasions and stress from capture and handling. Juvenile salmonids could be gilled in nets and suffer
29 from predation during capture. Common hook and line injuries are damage to skeletal structure of
30 the mouth, injury to gills, and secondary infections (National Marine Fisheries Service 2003). Except
31 in very severe cases, electrofishing injuries to juvenile salmonids heal and seldom result in
32 immediate or imminent mortality (Snyder 2003). Striped bass monitoring at Knights Landing using
33 fyke traps caught two adult steelhead in 16,100 hours; gillnetting on the lower Sacramento resulted
34 in one steelhead mortality in 15,450 hrs. (Dubois and Mayfield 2009; Dubois et al. 2010). Hook and
35 line removal of striped bass in the Carmel River Lagoon for 143 hours resulted in the capture of
36 seven steelhead to 112 striped bass (California Department of Fish and Game 2010a).

37 The effectiveness of a predator removal program is uncertain, as illustrated by the mixed results
38 achieved by other programs. Sustaining the potential benefits of predator reduction is challenging in
39 open systems such as rivers. On the Colorado River, predator removal programs failed to
40 significantly improve the situation of native fish, with only three of nine projects reporting a
41 decrease in large nonnative predators (Mueller 2005). The main problem was rapid recolonization
42 of treatment zones by new predators. Successful programs were limited to situations in isolated
43 waters that lacked predator recruitment from outside sources, and where targeted invasive species
44 had low reproductive rates and were easy to capture.

1   In the Lower Columbia River, a sustained predator reduction program has been implemented since
2   1990 to reduce the abundance of northern pikeminnow (Porter 2010; Independent Scientific
3   Review Panel 2011). Salmonids comprise 64% of prey fish in pikeminnow downstream of
4   Bonneville Dam (Porter 2011). Modeling simulations indicated that if predator-size northern
5   pikeminnow were exploited at a 10 to 20% rate, the resulting restructuring of their population
6   could reduce their predation on juvenile salmonids by 50%. The program uses a reward bounty for
7   anglers and has tested but discontinued other methods (gillnetting, longline, purse seine, trapnet) as
8   inefficient at the system-wide scale. Over a 20 year period, the program has achieved 10 to 20%
9   exploitation rates on large northern pikeminnow, which are the most predaceous, and an estimated
10   40% reduction in modeled predation on outmigrating smolts compared to preprogram levels
11   (Independent Scientific Review Panel 2011). However, no attempt has been made to relate predator
12   reduction to adult return rates (Independent Scientific Review Panel 2011). The efficacy of the
13   pikeminnow management program depends on the lack of compensatory response by other
14   piscivores such as smallmouth bass. Previous evaluations have not detected responses by the
15   predator community to sustained pikeminnow reduction, although responses to fisheries
16   management programs may not be detected for several years.

17   In general, to be successful, programs require a sustained level of effort at predator removal. In
18   addition, those programs that were successful involved isolated, small or closed systems that could
19   be thoroughly treated and where recolonization by predators could be controlled (e.g., Marks et al.
20   2010). Preventing recolonization would be very difficult or infeasible in most areas of the Delta.

21   ## 5.F.5.3.1.5   CM16 Nonphysical Fish Barriers

22   Nonphysical barriers are designed to guide juvenile salmonid fish away from migration routes with
23   low survival and high predation risk, such as the head of Old River and Georgiana Slough. Tools such
24   as the Delta Passage Model are used to assess reach-specific mortality rates. This model
25   incorporates studies of tagged juvenile smolts to estimate mortality in different reaches, presumably
26   by predation losses (detailed in Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*). In addition, the
27   physical infrastructure of the nonphysical barrier itself or other local features may attract
28   piscivorous fish to the area and increase localized predation risks.

29   In 1993, a preliminary field demonstration project was conducted to evaluate the feasibility and
30   effectiveness of a nonphysical acoustic (sound) barrier in deterring juvenile Chinook salmon
31   migrating down the Sacramento River from entering Georgiana Slough. Initial results were
32   promising and a more thorough evaluation followed, which included predation studies using
33   juvenile Chinook salmon as prey exposed to underwater sound. Results of these early studies
34   suggest that predation of juvenile Chinook salmon did not increase significantly following exposure
35   to the acoustic barrier signal (Hanson and San Luis & Delta-Mendota Water Authority 1996). Studies
36   on the nonphysical barrier at the head of Old River indicate that the barrier is effective at deterring
37   salmon smolts from entering the Old River. A 2009 study found the deterrence rate to be as high as
38   81% (Bowen et al. 2009) while a follow-up study in 2010 found the deterrence rate to be 23%.
39   However, many predators are attracted to a nearby deep scour hole immediately downstream of the
40   Old River split on the San Joaquin River and a large in-water structure. In fact, while the nonphysical
41   barrier deterrence rate was 81% in 2009, the predation rate was so high that the juvenile salmon
42   survival rate was not statistically different whether the barrier was on or off (Bowen et al. 2009).

43   Acoustic-tagging studies have shed light on a predation hotspot at the scour hole downstream of the
44   San Joaquin River and head of Old River (Bowen and Bark 2010; Vogel 2010, 2009; San Joaquin

1   River Group Authority 2011). Bowen and Bark (2010) suggested that much of the gain accomplished
2   by deterring salmon smolts from entering Old River was offset by heavy predation in the vicinity of
3   the scour hole. In 2010, Bowen and Bark (2010) estimated a 23% predation loss rate in the reach at
4   the head of Old River, while the Vernalis Adaptive Management Plan (VAMP) studies reported a 9%
5   mortality rate in that reach (San Joaquin River Group Authority 2011). Vogel (2010) evaluated the
6   movements of acoustic-tagged juvenile salmon released in the San Joaquin River and noted that
7   some areas where relatively high numbers of transmitters were located tended to be in the vicinity
8   of scour holes. Although substantial predatory fish activity and acoustic-tagged salmon (or
9   transmitters) inside predators were believed to occur in the area of the scour hole just downstream
10 of the head of Old River, the results of Vogel's study suggested that predatory fish did not reside in
11 the scour hole for extended periods (Vogel 2010). Nonetheless, there may be risks associated with
12 the installation of nonphysical barriers in that the benefits of deterrence by these highly efficient
13 structures may be offset by predation at such geomorphic features as scour holes. The scour hole at
14 the head of Old River is a proposed site for targeted removal of predators under CM15, possibly by
15 purse seining.

16 An analysis of potential predation effects on juvenile Chinook salmon at nonphysical barriers can be
17 done based on (1) size of barrier and (2) predicted predator abundance based on field surveys
18 (Vogel 2008; Bowen et al. 2009; Bowen and Bark 2010). This estimate is based solely on the size of
19 in-water structures from the barrier itself and does not include other predator aggregations nearby,
20 such as scour holes or other large in-water structures. At Georgiana Slough, nonphysical acoustic
21 barriers tested were approximately 185 meters long in 1993 (Hanson and San Luis & Delta-Mendota
22 Water Authority 1996) and 213 meters long in 2011–2012 (ICF International 2010). At the head of
23 Old River, nonphysical barriers being tested were 112 meters long in 2009 (Bowen et al. 2009) and
24 136 meters long in 2010 (Bowen and Bark 2010). It is assumed that nonphysical barriers
25 implemented for BDCP will be similar in size, ranging from 112 to 213 meters in length.

26 Estimates of predator abundance and predation rates were developed from fish screen studies
27 conducted at GCID (Vogel 2008). This estimate of predator density used for this simple analysis
28 likely overestimates predator presence at nonproject barriers because it is based on a large, tall
29 water diversion intake, compared to the minimal structures used to construct the nonproject
30 barriers at head of Old River and at Georgiana Slough. Median predator abundance associated with
31 these barriers would range from 44 to 83 fish (at a density of 0.39 predators per meter of intake, or
32 0.12 predators per foot of intake structure) with a median predation rate of 0.01 juvenile salmonid
33 per day. Over the course of a 150-day smolt outmigration period, it was assumed that between 66
34 and 125 juvenile salmonids would be lost to predation annually at nonphysical barriers as a result of
35 the increased holding habitat for piscivorous predators around the in-channel structures. Thus, the
36 impact of predation associated with nonphysical barrier structures would have an extremely minor
37 negative effect on the Chinook salmon population.

38 Ongoing studies at Georgiana Slough (2011 and 2012) will shed light on predator distribution and
39 behavior associated with the nonphysical barriers (ICF International 2010). Although the 2011 pilot
40 study did not focus specifically on predation effects of the nonphysical barrier structure, acoustically
41 tagged predators captured in the vicinity of the nonproject barrier did not appear necessarily
42 attracted to the structure (Reeves pers. comm.). The spring 2012 study compared the behavior of
43 tagged predators before and after installation of the barrier, but analysis has not yet been completed
44 (Reeves pers. comm.).

1 ### 5.F.5.3.1.6   CM21 Nonproject Diversions

2 Reduced entrainment of salmon and steelhead in unscreened nonproject diversions (e.g., small
3 agricultural diversions) is discussed in Appendix 5.B, *Entrainment*. While fish may benefit from new
4 screens that reduce entrainment at nonproject diversions, there may be some predation risk due to
5 new structural components (e.g., screens, support beams, trash racks) necessary for the screen
6 installations. Although most nonproject diversions are relatively small, they do require structural
7 components (e.g., support beams, intake pipes) that could provide suitable cover or holding areas
8 for predators. Consolidation and reduction of diversion intakes could reduce potential cover
9 elements for predators.

10 Moyle and Israel (2005) evaluated a number of fish screen projects in the Sacramento–San Joaquin
11 River system. Two studies suggested that some screens increased predation rates on juvenile
12 Chinook salmon by providing holding areas for predatory fish, but Moyle and Israel (2005) found
13 these inconclusive. While some screens may be detrimental because of predation on juvenile
14 salmon, the effect of individual diversions is likely highly variable, depending on size and location.
15 Insufficient information exists to support conclusions regarding the likelihood of predation
16 associated with these structures.

17 ## 5.F.5.3.2   Delta Smelt

18 ### 5.F.5.3.2.1   CM1 Water Facilities and Operation

19 Reduced exports in the south Delta will reduce the amount of water, and therefore the number of
20 delta smelt, that will enter the CCF. Although the role of predation near the SWP and CVP south Delta
21 pumping facilities in the dynamics of Delta fish populations is not well understood, delta smelt are
22 likely to be highly vulnerable to predation in this area, where they are entrained and predators
23 aggregate (Sommer et al. 2007; U.S. Fish and Wildlife Service 2008; Miranda et al. 2010), especially
24 in the CCF. Predation in the forebay during the entrainment and salvage process is thought to
25 contribute substantially to overall losses associated with the SWP export facilities. A pilot study of
26 tagged delta smelt estimated pre-screen losses greater than 90% (Castillo et al. in press). Delta smelt
27 face losses due to predation and handling even after they are salvaged at the fish facilities. Very few
28 entrained smelt escape the high level of predation long enough to be released back into the Delta
29 and survive. Therefore, reducing the number of fish entrained to the facilities would reduce the
30 effect of predation on the delta smelt population.

31 Periodic bass sportfishing tournaments are proposed under CM15 to achieve intensive removal
32 efforts, while limiting program costs and potential by-catch issues. These efforts are expected to
33 lower predation losses of entrained juvenile and adult delta smelt. However, sustaining reduced
34 predator abundances in the forebay is expected to be difficult because of the large area, continual
35 influx of predators through the radial gates, and incidental take of covered fish entrained into the
36 forebay.

37 Entrainment and exposure to predation were calculated based on the OMR Proportional Loss model
38 by Kimmerer (2008), which calculates smelt entrainment as a proportion of OMR flows. The
39 numbers of delta smelt juveniles and larvae (Table 5.F.6-10) and adults (Table 5.F.6-11) entrained
40 and therefore exposed to predation at the SWP and CVP facilities are substantially reduced in all
41 water-year types under CM1 (ESO_ELT and ESO_LLT) compared to existing biological conditions
42 (EBC2_ELT and EBC2_LLT). Average entrainment loss across all water-year types was reduced by 36

1   to 40% for larval and juvenile delta smelt, and 27 to 28% for adults (although the actual number of

2   fish is low in both the EBC and ESO scenarios). The reduction in entrainment was greater in wetter

3   water-year types for both life stages and time scenarios (Table 5.F.6-11). Because predation is high

4   once smelt are entrained, a decrease in entrainment should reduce total predation losses by a large

5   margin.

6   **Table 5.F.6-10. Average Estimated Change in Annual Proportional Loss of Juvenile and Larval Delta**
7   **Smelt at SWP/CVP South Delta Export Facilities by Water-Year Type for the Study Scenarios, Using**
8   **Estimates Based on Kimmerer (2008)**

WY Type	EBC2 vs. ESO_ELT	EBC2 vs. ESO_LLT	EBC2_ELT vs. ESO_ELT	EBC2_LLT vs. ESO_LLT
All	-0.039 (-39%)	-0.046 (-47%)	-0.033 (-36%)	-0.035 (-40%)
Wet	-0.046 (-51%)	-0.051 (-56%)	-0.043 (-49%)	-0.046 (-54%)
Above Normal	-0.043 (-40%)	-0.044 (-41%)	-0.032 (-33%)	-0.025 (-28%)
Below Normal	-0.03 (-27%)	-0.042 (-38%)	-0.024 (-23%)	-0.033 (-33%)
Dry	-0.038 (-34%)	-0.052 (-47%)	-0.032 (-31%)	-0.039 (-40%)
Critical	-0.031 (-40%)	-0.034 (-45%)	-0.026 (-36%)	-0.020 (-32%)

9

10   **Table 5.F.6-11. Average Change in Estimated Annual Proportional Loss of Adult Delta Smelt at**
11   **SWP/CVP South Delta Pumps by Water-Year Type for the Study Scenarios**

WY Type	EBC2 vs. ESO_ELT	EBC2 vs. ESO_LLT	EBC2_ELT vs. ESO_ELT	EBC2_LLT vs. ESO_LLT
All	-0.025 (-28%)	-0.027 (-30%)	-0.023 (-27%)	-0.023 (-28%)
Wet	-0.049 (-64%)	-0.048 (-62%)	-0.047 (-63%)	-0.045 (-61%)
Above Normal	-0.035 (-38%)	-0.037 (-40%)	-0.035 (-38%)	-0.036 (-40%)
Below Normal	-0.019 (-20%)	-0.019 (-21%)	-0.018 (-19%)	-0.017 (-18%)
Dry	-0.001 (-1%)	-0.007 (-7%)	-0.001 (-1%)	-0.003 (-4%)
Critical	-0.003 (-4%)	-0.009 (-10%)	-0.000 (0%)	-0.002 (-2%)

12

13   At the new north Delta intakes, while there is the potential that the structures associated with the

14   facilities may attract fish predators, the overall impact of predation to delta smelt is low because this

15   area is located upstream of their range. The predicted effect of predator removal around the new

16   north Delta intakes is discussed below in Section 5.F.5.3.2.4, *Predator Removal (Conservation*

17   *Measure 15)*.

18   **5.F.5.3.2.2   Habitat Restoration (CM2, CM4, CM5, CM6, and CM7)**

19   *CM6 Channel Margin Enhancement* will remove structures and riprap along levees in the Delta.

20   These structures represent habitat that attract predators such as Sacramento pikeminnow or

21   centrarchids. Larval and juvenile delta smelt have been observed in nearshore habitats, although

22   they are found predominantly in open channel habitats (Nobriga et al. 2005). The importance of

23   channel margin habitat for juvenile delta smelt rearing therefore is unknown. The effectiveness of

24   channel margin enhancement measures in reducing delta smelt predation also depends on whether

25   these restored areas are invaded by nonnative IAV. Tidal habitat restoration measures (*CM2 Yolo*

26   *Bypass Fisheries Enhancement, CM4 Tidal Natural Communities Restoration, CM5 Seasonally*

27   *Inundated Floodplain Restoration*) are not expected to notably reduce predation risk for delta smelt

1   as these habitats are typically in shallow-water areas not associated with the pelagic nature of delta
2   smelt.

5.F.5.3.2.3   CM13 Invasive Aquatic Vegetation Control

4   Removal of IAV likely would improve conditions for delta smelt by removing the aquatic vegetation
5   associated with a decrease in turbidity. Increased turbidity is associated with improved
6   concealment for delta smelt to avoid detection from mainly visual predators like largemouth bass
7   and striped bass. IAV removal also should increase available shallow-water habitat for juveniles,
8   although it is unknown how much juvenile delta smelt use these habitats. The effect on adult delta
9   smelt is likely to be small, because adults are mostly pelagic and not likely to use shallow-water
10   habitats typically associated with dense IAV. It is thought that spawning of delta smelt occurs over
11   sandy areas at subtidal elevations, where SAV is known to occur. Removal of SAV therefore may
12   increase the habitat available for spawning.

5.F.5.3.2.4   CM15 Localized Reduction of Predatory Fishes

14   To the extent localized predator reduction efforts reduce the overall abundance of pelagic predators
15   in the Delta occupied by delta smelt, it is expected that there would be some reduction in losses to
16   predation, although very limited quantitative information is available regarding the current
17   magnitude of delta smelt loss to predation. In general, delta smelt are most likely to benefit from
18   actions that involve removal of migratory, pelagic predators (e.g., striped bass) from the system
19   compared to other predator management actions for the reasons below. Large fish such as striped
20   bass though may not be the main predators of delta smelt; egg and larval delta smelt are very
21   vulnerable to predation by small fish such as inland silversides. Therefore removal of large
22   predators may have minimal benefit for delta smelt if predation loss predominantly occurs during
23   the egg and larval life stages.

24   Furthermore, predator removal actions may have limited benefit for delta smelt because:

25   ●   Some predator removal actions will occur upstream of smelt habitat.

26   ●   Removal of migratory, pelagic predators from anywhere in the system has the potential to
27   reduce predation pressure on smelt because these predators are likely at some point to move
28   into smelt habitat.

29   ●   Some anticipated actions will involve modifications to nearshore habitats, whereas smelt are
30   more likely to inhabit open-water habitats and rarely associate with structures (Moyle 2002).

31   The only available quantitative information that relates to striped bass predation on delta smelt
32   populations is from CDFW (California Department of Fish and Game 1999) and re-analysis of these
33   data by Hanson (2009). CDFW (California Department of Fish and Game 1999) estimated that, based
34   on the mean 1992–1994 abundance of Age-1 through Age-3+ striped bass (approximately 7 million)
35   and the 1994 estimate of smelt abundance (approximately 5 million), striped bass annually consume
36   0.71 delta smelt per striped bass per year or roughly 250,000 individuals annually (about 5% of the
37   delta smelt population). Hanson (2009), using similar data but different methods, estimated higher
38   levels of striped bass predation on delta smelt (approximately 13% annually). There is a high level
39   of uncertainty associated with both of these analyses (Hanson 2009). However, these estimates
40   provide a basis for characterizing the general magnitude of the reduction in smelt loss to striped
41   bass predation due to localized predator removal efforts.

1   The assumptions of theoretical level of predator removal effort are described in Section 5.F.5.3.1.4,
2   *Predator Removal (Conservation Measure 15)*. Based on these estimates, it is presumed that roughly
3   9,000 Age-1 and older striped bass would be removed from the system annually. As noted before,
4   the level of removal effort though would be subject to change based on findings from the CM15 pilot
5   program and research program. Given the consumption rates above and the assumed level of
6   predator removal effort, this theoretically would reduce the number of juvenile and adult smelt lost
7   to striped bass predation during the first year of full implementation by approximately 66,000 fish.

8   There are several caveats to the above calculations on the effectiveness of predator removal. Striped
9   bass in particular will be difficult to control locally because they are highly mobile and can quickly
10   recolonize areas. Problems arising from rapid recolonization by mobile predatory species have been
11   observed in previous predator removal programs (Mueller 2005; Cavallo et al. 2012). Also the above
12   hypothetical predator removal program assumes constant density of delta smelt at the predator
13   removal locations during October–June. Because largemouth bass and striped bass are highly
14   opportunistic feeders, their rate of predation on delta smelt will be proportional to the density of
15   smelt present. Therefore, the benefits of predator removal for delta smelt will be realized only
16   during the times delta smelt are present at those sites in appreciable numbers. The assumed
17   consumption of delta smelt by striped bass may be overestimated, as delta smelt are currently less
18   common than they were when the studies cited above were performed, and Nobriga and Feyrer
19   (2007) did not observe littoral predators consuming any delta smelt. It is noted that the expected
20   number of striped bass removed is small relative to the total population and annual fluctuations in
21   the population, so the effect of removal on the population size of striped bass may not be discernible.
22   Finally, the assumptions provided above regarding the number of striped bass that can be captured
23   during removal efforts are speculative, but based on the best available information, professional
24   judgment, and experience with past similar efforts. The numbers captured in practice likely will vary
25   substantially with the methods employed, and according to the season and sampling conditions at
26   the removal sites selected. A potential risk of localized predator removal is bycatch of delta smelt
27   during electrofishing, fyke netting, or other capture methods meant to remove predators.

5.F.5.3.2.5   CM16 Nonphysical Fish Barriers

29   Delta smelt are known to occupy areas in the Sacramento River upstream of Georgiana Slough and
30   in the San Joaquin River upstream of the head of Old River, although they are found predominantly
31   downstream of these areas. Nonphysical barriers in the Delta are not specifically designed to alter
32   delta smelt migration, rather they are designed primarily to alter salmonid migration and are
33   typically operational only during the juvenile salmonid emigration period, which ends around May.
34   Juvenile delta smelt emigration occurs mostly in May and June, so there may be limited overlap in
35   timing with the juvenile salmonid migration.

36   Research in the early 1990s using a nonphysical barrier in the Delta was focused on the use of an
37   acoustic (sound) barrier to deter juvenile salmon from entering Georgiana Slough and found that
38   delta smelt exposed to the sound signal at this barrier (60-minute exposure at 6 feet) did not show
39   increased mortality from controls (91% survival for exposed smelt and 89% for the control smelt)
40   (Hanson and San Luis & Delta-Mendota Water Authority 1996). At the time it was speculated that
41   acoustic barrier operations might cause delta smelt to avoid otherwise suitable spawning habitat,
42   could create a blockage, delaying the upstream migration of adult delta smelt, might adversely affect
43   the hatch of delta smelt eggs spawned near the barrier (Hanson and San Luis & Delta-Mendota
44   Water Authority 1996).

1   Recent investigations into the effects of nonphysical fish barriers in the Delta have focused on
2   deterring juvenile salmon at the head of Old River (Bowen et al. 2009; Bowen and Bark 2010) and
3   Georgiana Slough (ICF International 2010). Affects of these barriers on delta smelt have not been
4   specifically investigated. Delta smelt juveniles have only limited swimming ability, so it is unknown
5   whether delta smelt have the escape ability to be deterred by and avoid the nonphysical barriers,
6   especially in years with high flow rates. The in-water structures associated with these barriers may
7   attract fish predators, however, increasing localized predation risk for delta smelt migrating past the
8   barriers. The scour hole on the San Joaquin River, downstream of the nonphysical barrier at the
9   head of Old River is associated with high abundances of migratory striped bass predators. These
10 nonphysical barriers and scour holes like the one near the head of Old River may be targets of
11 localized predator reduction measures (CM15), which may help mitigate the potential predation risk
12 to delta smelt.

5.F.5.3.2.6   CM21 Nonproject Diversions

14 The extent that delta smelt are entrained in unscreened nonproject diversions (e.g., small
15 agricultural diversions) along with the benefits and risks relative to entrainment reduction
16 associated with this conservation measure has been discussed in Appendix 5.B, *Entrainment*.

17 The predation-related effects of nonproject diversions on delta smelt relate to the cover provided
18 for predatory fish by the intake structures. Additional structural components (e.g., screens, support
19 beams, trash racks) required for screening nonproject diversion could attract predatory fish. On the
20 other hand, consolidation and removal of small diversions could reduce cover for predators. The
21 magnitude of effect would depend in part on the spatial overlap of nonproject diversions and delta
22 smelt.

5.F.5.3.3   Longfin Smelt

5.F.5.3.3.1   CM1 Water Facilities and Operation

25 The potential benefits and risks for longfin smelt would be similar to those outlined above for delta
26 smelt, although their magnitude may be reduced because longfin smelt occupy a smaller proportion
27 of Delta habitat and for a shorter proportion of their life history.

28 Entrainment improves in wetter years, but worsens in drier years under CM1. Most entrainment of
29 longfin smelt though occurs in the drier water-year types (Appendix 5.B, *Entrainment*). Entrainment
30 of longfin smelt, especially in the CCF, may be associated high predation losses. No quantitative
31 assessment of the rate of predation loss for longfin smelt in the forebay has been conducted, but it is
32 assumed to be similar to the high loss experienced by juvenile and adult delta smelt. It was
33 presumed that predation loss of juvenile and adult longfin smelt was 75% and 15% at the SWP and
34 CVP facilities, respectively. The amount of change in predation loss of longfin due to changes of
35 entrainment under CM1 is shown in Table 5.F.6-12. Entrainment in the early long-term for juvenile
36 longfin smelt is increased but relatively unchanged for late long-term. Entrainment for adult longfin
37 smelt is virtually unchanged under CM1, because total entrainment of adult longfin smelt in the
38 south Delta export facilities is small.

1   **Table 5.F.6-12. Total Predation Losses of Longfin Smelt under CM1**

Longfin Smelt	Existing Conditions ELT (EBC2_ELT)	Existing Conditions LLT (EBC2_LLT)	CM1 ELT (ESO_ELT)	CM1 LLT (ESO_LLT)	EBC2_ELT vs. ESO_ELT	EBC2_LLT vs. ESO_LLT
Juvenile	203,000	205,000	126,000	118,000	-77,000	-87,000
Adult	131	127	71	69	-60	-58
Note: Based on assumption of 75% predation loss of juvenile and adult longfin smelt in SWP and 15% predation loss in CVP.						

2

3   Longfin smelt are not expected to be near the north Delta intakes and hence not affected by the
4   potential increase abundance of predators around the intake structures. Recent abundance and
5   distribution survey data are not available for this region for longfin smelt, but previous studies
6   indicate that this species is rarely distributed upstream of Rio Vista on the Sacramento River (Moyle
7   2002), although this may change in the future because of climate change.

8   ### 5.F.5.3.3.2   Habitat Restoration (CM2, CM4, CM5, CM6, and CM7)

9   Because of longfin smelt preference for deeper waters, shallow-water habitat restoration is not
10   expected to affect longfin smelt predation risks. Only a relatively small proportion of the juvenile
11   population may use the shallow-water habitats in Cache Slough, Suisan Marsh, and the Yolo Bypass
12   targeted for restoration (Moyle 2008). For the small number of juveniles that do rear in the areas,
13   the risk of predation greatly depends on whether these habitats become recolonized by IAV and
14   hence predators like largemouth bass.

15   ### 5.F.5.3.3.3   CM13 Invasive Aquatic Vegetation Control

16   The effect of IAV removal on predation risk for longfin smelt is expected to be similar to that for
17   delta smelt. Longfin smelt are found predominantly in deeper water habitats and do not commonly
18   occupy shallow waters where IAV is found. For the small proportion of juveniles that do inhabit
19   these shallow areas, removal of IAV likely will reduce presence of largemouth bass and hence reduce
20   predation effects on longfin smelt. Removal of IAV is predicted to increase turbidity in the Delta,
21   which should increase cover for longfin smelt for concealment from piscivorous predators.

22   ### 5.F.5.3.3.4   CM15 Localized Reduction of Predatory Fishes

23   The benefits and risks to longfin smelt from predator removal measures are expected to be similar
24   to the effects predicted for delta smelt (Section 5.F.3.5.2.4).

25   ### 5.F.5.3.3.5   CM16 Nonphysical Fish Barriers

26   Nonphysical barriers in the Delta are intended to guide juvenile fish away from migration routes
27   with low survival and high predation risk, such as the head of Old River in the southeastern Delta
28   and Georgiana Slough in the north Delta. Locations currently under consideration for the installation
29   of nonphysical barriers are not likely to overlap the spatial distribution of juvenile and adult longfin
30   smelt, which rarely are found upstream of Rio Vista or Medford Island (Moyle 2002) in the western
31   and central Delta, respectively. Therefore, benefits are considered negligible at best. In addition,
32   nonphysical barriers are not specifically designed to alter longfin smelt migration routes; hence,
33   they likely will not operate to deter smelt from entering parts of the Delta with high predation rates.
34   However, the structures associated with nonphysical barriers may attract fish predators, increasing

1 the predation risk for longfin smelt that might encounter them. These barriers may be a target of
2 localized predator reduction measures (CM15) that may help mitigate the predation risk to longfin
3 smelt.

5.F.5.3.3.6   CM21 Nonproject Diversions

5 The extent of longfin smelt entrainment in unscreened nonproject diversions (e.g., small agricultural
6 diversions) is discussed in Appendix 5.B, *Entrainment.* The benefits and risks to longfin smelt from
7 agricultural diversion screening and consolidation are expected to be similar to the effects predicted
8 for delta smelt (Section 5.F.5.3.2.6).

5.F.5.3.4   Sacramento Splittail

5.F.5.3.4.1   CM1 Water Facilities and Operation

11 Juvenile and subadult splittail have been observed in fish salvage operations at both the SWP and
12 CVP fish salvage facilities. No studies have been performed, however, to assess the vulnerability of
13 juvenile and subadult splittail to predation in the CCF. Based on their size, it has been assumed for
14 purposes of this effects assessment that splittail would be vulnerable to predation in a manner
15 similar to that observed for juvenile salmon, striped bass, and steelhead (Gingras 1997; Clark et al.
16 2009). Therefore, the risk of predation mortality in the CCF is assumed to be approximately 75%,
17 and the risk of predation associated with the CVP trash racks is assumed to be 15%. After splittail
18 are salvaged at the export facilities, they experience predation by piscivorous fish and bird
19 predators at the salvage release locations in the Delta. *CM15 Localized Reduction of Predatory Fishes*
20 will increase the number of release sites from four to eight and remove debris near salvage release
21 sites monthly from October through June to reduce the predation loss of salvaged splittails and
22 other fish once released.

23 Juvenile splittail would be vulnerable to increased predation mortality in the vicinity of the
24 proposed north Delta intake locations during their emigration from upstream spawning habitats on
25 the Sacramento River such as the Sutter Bypass. Splittail do not appear to be a substantial part of the
26 diet of striped bass around the Sacramento River reach where the proposed north Delta intakes
27 would be sited. Results of striped bass diet studies conducted by Thomas (1967) showed that no
28 splittail were observed in the striped bass sampled. Stevens (1963) also conducted diet studies on
29 striped bass in the reach of the Sacramento River upstream of Rio Vista and found splittail in the diet
30 of striped bass. However, he reported only 1.4% of the striped bass stomachs that contained food
31 had splittail, representing 1% of the diet of striped bass in July. Splittail were not observed by
32 Stevens in the diet of striped bass in other months of the year. For purposes of this effects analysis, it
33 is assumed that juvenile splittail would be vulnerable over a 4-month period in the late spring and
34 summer (April–July) when, on average, nearly all juvenile splittail emigrate. Localized predator
35 reduction measures (CM15) are being proposed for the north Delta sites to reduce the risk of
36 predation on splittail and other covered fishes.

37 The bioenergetics model developed by Loboschefsky and Nobriga (2010) was used to estimate
38 predation of splittail at the north Delta intakes. The methods for this bioenergetics approach for
39 determining splittail predation loss are the same as those for the juvenile salmon bioenergetics
40 analysis, except that splittail abundance and splittail fork length estimates were calculated on a
41 monthly average instead of weekly. Under the assumption of intake density of 119 striped bass per
42 1000 feet on intake (3 intakes with a total intake length of 5,650 feet) about 1,390,000 splittail are

1   consumed by striped bass in the early long-term and about 1,463,000 splittail are consumed in the
2   late long-term with no predator reduction. If predator reduction under CM15 was effective at
3   removing 15% of the predators around the north Delta intakes (only 571 total predators instead of
4   672), the number of splittail consumed would decrease to 1,182,000 in the early long-term and
5   1,243,000 in late long-term (Table 5.F.6-13). The effect of a 15% predator removal may be
6   understated, if targeted removal is more effective at removing larger, more piscivorous fish
7   predators than the smaller, younger predators.

8   **Table 5.F.6-13. Number of Sacramento Splittail Consumed by Striped Bass at North Delta Intakes with**
9   **and without Localized Predator Reduction (15% Removal)**

Striped Bass Numbers		Splittail Consumed (Estimated Number)				Reduction in Splittail Predation losses	
Per 1,000 Feet of Intake	Total	Without Predator Reduction		With Predator Reduction			
		ESO_ELT	ESO_LLT	ESO_ELT	ESO_LLT	ESO_ELT	ESO_LLT
18 (Low)	102	210,000	221,000	179,000	188,000	32,000	33,000
119 (Median)	672	1,390,000	1,463,000	1,182,000	1,243,000	209,000	219,000
219 (High)	1,237	2,559,000	2,692,000	2,175,000	2,288,000	384,000	404,000

10

11   Unlike Chinook salmon, absolute abundance estimates have not been developed for the Sacramento
12   splittail population. Therefore, a predation mortality rate as a proportion of the total population
13   cannot be estimated for splittail. However, numbers of splittail salvaged at the SWP and CVP export
14   facilities in the south Delta have been estimated, and past studies have found no evidence that
15   entrainment of juvenile splittail by CVP and SWP facilities significantly affects splittail abundance
16   (Sommer et al. 1997; Moyle et al. 2004). Some entrainment at the south Delta export facilities would
17   continue after the north Delta diversions began operating. Nevertheless, it is reasonable to conclude
18   that if projected number of splittail lost to predation at the north Delta diversion intakes is small
19   relative to the numbers lost due to south Delta exports under current conditions, the predation at
20   the north Delta intakes is unlikely to significantly affect the splittail population. However, if the
21   projected number of splittail lost to predation at the north Delta diversion intakes is similar to or
22   larger than the number lost due to south Delta exports under current conditions, the significance of
23   the predation would be difficult to assess.

24   At the south Delta export facilities the overall average May through July salvage for the 1980 to 2008
25   period is about 634,000 splittail, with an average of 1,200,000 splittail for wet years (Wet and Above
26   Normal water-year types combined) and about 24,000 splittail for dry years (Below Normal, Dry
27   and Critical water-year types combined). For Chinook salmon, on average, approximately three fish
28   are assumed to be killed for every fish salvaged at the SWP and CVP facilities as a result of pre-
29   screen mortality (primarily predation), louver inefficiencies, handling losses and post-release
30   mortality (National Marine Fisheries Service 2009). Assuming these losses are similar for splittail,
31   the total entrainment losses for splittail are about 2,500,000 splittail for all years, 4,800,000 in wet
32   years, about 97,000 in dry years.

33   The north Delta diversions consumption estimates are generally similar or lower than south Delta
34   entrainment losses, except in dry water-year types. Not including the dry water-year types, the
35   projected consumption rates (ESO_LLT with low and median predator densities) range between 9 to
36   58% of entrainment losses in all years averaged and 5 to 30% of the entrainment losses in wet
37   years. In the dry water-year types, the modeled consumption rate is approximately 2 to 15 times

1   greater than south Delta entrainment losses. However, these results are likely to be misleading
2   because few splittail are expected to be present near the north Delta intakes in dry years, so
3   consumption would be much lower than bioenergetics model estimates, which are based solely on
4   striped bass feeding rates. The effect of predation losses at the intakes at a population level for
5   splittail is highly uncertain.

6   5.F.5.3.4.2   Habitat Restoration (CM2, CM4, CM5, CM6, and CM7)

7   The effect on splittail predation risk from proposed habitat restoration is unknown, but the general
8   effect is expected to be similar to that for salmon and steelhead. Both juvenile and adult splittail are
9   known to readily occupy shallow-water habitats; therefore, the efforts to restore shallow tidal
10   habitats, seasonal wetlands, and channel margins likely will be beneficial to the species. However, if
11   these restored areas are recolonized by IAV, splittail may suffer increased predation risks from
12   predators like largemouth bass.

13   All life stages of splittail on the Yolo Bypass floodplain are vulnerable to predation from catfish,
14   centrarchids, and birds, but the high turbidity often found on the floodplain may reduce predation
15   risk (Sommer et al. 2008). The risk to splittail in restored shallow-water tidal zones and floodplains
16   depends on how readily piscivorous predators use these areas (see Section 5.F.5.3.1.2 for benefits
17   and risks to Chinook salmon and steelhead). Harrell and Sommer (2003) used fyke traps to
18   determine that adult striped bass and adult splittail were present in the winter and spring months in
19   a perennially flooded portion of the Yolo Bypass. Feyrer and coauthors (2006) analyzed seasonally
20   inundated floodplain habitat in the Yolo Bypass using rotary screw traps and found striped bass in
21   only 22% of samples and largemouth bass in 12% of samples. Most of the occurrence of striped bass
22   in the Yolo Bypass occurred in June, by which time most covered juvenile fishes have migrated from
23   the area. Chinook salmon and splittail represented 79% of all individuals collected in the
24   intentionally inundated floodplains, suggesting that floodplain habitat restoration benefits native
25   fish species like splittail more than nonnative fish predators (Feyrer et al. 2006).

26   5.F.5.3.4.3   CM13 Invasive Aquatic Vegetation Control

27   Benefits and risks to Sacramento splittail from CM13 are assumed to be similar to those described
28   for Chinook salmon (Section 5.F.5.3.1.4) based on the similar size of juvenile splittail and salmonids
29   in the Delta.

30   Removal of IAV would be expected to benefit splittail by reducing habitat for predators.

31   5.F.5.3.4.4   CM15 Localized Reduction of Predatory Fishes

32   Splittail are likely vulnerable to the three main large fish predators, because they are widely
33   distributed in the Delta and also utilize littoral areas to forage. Anecdotal observations indicate that
34   recreational anglers have collected and used splittail as bait to catch striped bass. Similarly, golden
35   shiner, a fish similar in size and body shape to a juvenile splittail, commonly are used as bait to catch
36   both striped bass and largemouth bass. It has been presumed, therefore, that splittail are actively
37   consumed by bass species.

38   Nobriga and Feyrer (2007) surveyed the diet of striped bass, largemouth bass, and pikeminnow in
39   the Delta and reported that splittail were present in only three out of 608 predators sampled (0.5%).
40   While it is reasonable to suspect predation of splittail does occur in the Delta, there is low certainty
41   of its significance to the species. While predator removal may reduce the level of predation losses of

1   splittail, the benefit of this action to the population is not known. There is also the potential to
2   initiate a compensatory release of other species of predatory fish, if only certain predators such as
3   largemouth bass and striped bass are targeted for removal. Targeted removal of predatory fish large
4   enough to prey on listed species could fail to reduce total predation losses of listed fishes in the
5   Delta as other nontargeted piscivorous fish populations increase in size. A potential risk of localized
6   predator removal is bycatch of splittail during electrofishing, fyke or gill netting, or other capture
7   methods meant to remove predators.

5.F.5.3.4.5   CM16 Nonphysical Fish Barriers

9   The benefits of the installation of nonphysical barriers to Sacramento splittail are unknown.
10   Although nonphysical barriers are constructed and operated mainly with salmonids in mind,
11   splittail also are likely to be deterred by the nonphysical barriers based on their hearing ability and
12   strong swimming ability as young juveniles. During wetter years, splittail may migrate up the
13   Sacramento and San Joaquin Rivers beyond the northern and southern boundaries of the Delta and
14   therefore are likely to encounter the nonphysical barriers at the head of Old River and Georgiana
15   Slough. Although nonphysical barriers likely will be operated to coincide mainly with the juvenile
16   salmonid emigration period, juvenile splittail outmigration to the Delta is most likely during April to
17   August (Moyle 2002). Therefore, the first months of the juvenile Sacramento splittail migration to
18   the Delta overlap the main juvenile salmonid outmigration period. If nonphysical barriers are
19   effective at deterring splittail from areas with high mortality rates, such as Georgiana Slough, the
20   risks of predation for juvenile splittail are reduced. The nonphysical barriers have the potential to
21   attract predatory fish, which often hold around underwater human-made structure. Therefore, there
22   is a slightly increased risk of predation for juvenile splittail in the area immediately around the
23   nonphysical barriers.

5.F.5.3.4.6   CM21 Nonproject Diversions

25   The extent to which Sacramento splittail are entrained in unscreened nonproject diversions (e.g.,
26   small agricultural diversions), along with the benefits and risks relative to entrainment associated
27   with this conservation measure, has been discussed in Appendix 5.B, *Entrainment*.

28   The benefits and risks to splittail from diversion screening and consolidation are expected to be
29   similar to the effects predicted for delta smelt (Section 5.F.5.3.2.6).

5.F.5.3.5   Green and White Sturgeon

5.F.5.3.5.1   CM1 Water Facilities

32   Reduced exports in the south Delta from the construction of the north Delta intakes, which would be
33   expected to reduce the number of sturgeon exposed to predation at the south Delta facilities, may
34   reduce net entrainment of green and white sturgeon. Increased presence of predators around the
35   north Delta intakes may increase predation loss of juveniles emigrating downstream to rear in the
36   Delta. Juvenile sturgeon begin to emigrate at a small size and may be small enough still to be preyed
37   upon by piscivorous fish as they pass by the north Delta facilities. Juvenile sturgeon grow very
38   rapidly early in their development. Green sturgeon juveniles reach up to 30 cm the first year and
39   exceed 60 cm in the first 2 to 3 years (Nakamoto et al. 1995). Their larger size and protective bony
40   plates (scutes) make them much less vulnerable to predation.

1   ## 5.F.5.3.5.2   Habitat Restoration (CM2, CM4, CM5, CM6, and CM7)

2   The creation of permanent tidal brackish habitat in Suisun Marsh would create permanent year-
3   round rearing habitat for juveniles of both species of sturgeon. Once these habitats become fully
4   established, they are expected to provide highly productive food and refuge habitats. Because of
5   their salinities, these habitats would be expected to provide some refuge from black bass. Also,
6   because younger juvenile sturgeon are less tolerant of saltwater, juveniles that occupy these
7   brackish habitats are likely larger and have developed armored bony plating to substantially reduce
8   predation vulnerability. Predator reduction measures (CM15) may serve as a modest benefit to
9   protect small juvenile sturgeon that can be vulnerable to predation risks, but benefits can be
10   expected to be limited as sturgeon can quickly outgrow the hunting ability of the piscivorous
11   commonly fish found in the Delta.

12   ## 5.F.5.3.5.3   CM13 Invasive Aquatic Vegetation Control

13   The effect of IAV removal on predation risk for sturgeon is expected to be low. Larval and juvenile
14   sturgeon inhabit the lower reaches of the Sacramento River, San Joaquin River, and the Delta
15   (Stevens and Miller 1970), where they tend to concentrate in deeper areas of the estuary with soft
16   mud and sand substrate (Moyle 2002); these areas generally lack IAV and would not be areas
17   targeted for IAV removal. Sturgeon grow rapidly and can quickly outgrow the size range where
18   predation could occur (Nakamoto et al. 1995). Sturgeon also have protective scutes, making them
19   unappealing to predators even at a young age.

20   ## 5.F.5.3.5.4   CM15 Localized Reduction of Predatory Fishes

21   Little is known about predation of juvenile sturgeon in the Delta. Sturgeon grow rapidly in their first
22   year of development and grow protect bony plating at an early age. For example, white sturgeon
23   juveniles rearing in the Delta reach 18 to 30 cm fork length in their first year (Moyle 2002).
24   Likewise, young green sturgeon grow quickly in their first year, probably reaching 30 cm (12 inches)
25   in their first year (Kohlhorst and Cech 2001). Because of their rapid growth early in their
26   development (Nakamoto et al. 1995), the period in which juvenile sturgeon are vulnerable to
27   piscivorous fish predators in the Delta likely is limited.

28   Studies in the Columbia River basin show predation of very young juvenile sturgeon by northern
29   pikeminnow and prickly sculpin is quite common in upstream reaches (Miller and Beckman 1996).
30   Based on information from the Columbia River, it is presumed that predation of juvenile sturgeon in
31   the upper reaches of the Sacramento River basin is likewise common by Sacramento pikeminnow
32   and prickly sculpin. If most of the predation of juvenile sturgeon occurs in the upper Sacramento
33   River basin, predator reduction measures in the Delta may have little effect on reducing total
34   juvenile sturgeon predation losses. Sturgeon are benthic feeders which may limit their encounters
35   with pelagic predators like striped bass.

36   One potential risk of localized predator removal is bycatch of green and white sturgeon during
37   beach seining, gill netting, angling, electrofishing, and other capture methods. Sturgeon tend to
38   reside in deepwater areas and should be protected from electrofishing, but they would be more
39   susceptible to injury because of their large size. Striped bass monitoring by CDFW at Knights
40   Landing using fyke traps caught four adult green sturgeons in 16,100 hours; gill netting on the lower
41   Sacramento resulted in the capture of two green sturgeons in 15,450 hours (Dubois and Mayfield
42   2009; Dubois et al. 2010). Adult sturgeon are not susceptible to being caught using artificial lures
43   commonly used to catch striped bass but would be susceptible to baited hooks. Injuries to sturgeon

1   would be similar to those experiences by salmonids discussed above. Adult sturgeon in deep water
2   should be able to avoid most types of nets. Adult sturgeon caught in nets (fyke, beach seine, or gill
3   nets) could suffer injuries similar to salmonids.

5.F.5.3.5.5   CM16 Nonphysical Fish Barriers

5   The effect on sturgeon from predation associated with the construction of nonphysical barriers is
6   unknown. Green sturgeon are not known to spawn currently in the San Joaquin River, although they
7   may have historically (Moyle 2002; Beamesderfer et al. 2007). White sturgeon still spawn in the
8   lower San Joaquin River, although likely only in wet years (Moyle 2002; Beamesderfer et al. 2007).
9   Therefore, the level of interaction of sturgeon juveniles with the Old River nonphysical barrier is
10   likely to be minimal. Both green and white sturgeon are known to spawn upstream in the upper
11   Sacramento River basin (Moyle 2002), and emigrating juveniles likely will encounter the Georgiana
12   Slough barrier. Nonphysical barriers are likely to attract piscivorous predators hiding among the
13   physical structures of the barrier and may create an increased predation risk for small sturgeon
14   juveniles. Sturgeon are not deterred by the sounds and lights of the barrier, in part due to their lack
15   of specialized hearing structures and swimbladders, and therefore would not be deterred from
16   entering areas of the central Delta associated with high predation. Additionally, the head of Old
17   River and Georgiana Slough nonphysical barriers have been designed to allow passage of sturgeon
18   under the barrier structure.

5.F.5.3.5.6   CM21 Nonproject Diversions

20   The entrainment-related effects of screening or consolidating nonproject diversions on sturgeon are
21   discussed in Appendix 5.B, *Entrainment*. This conservation measure would likely have little or minor
22   benefit for sturgeon, since juveniles are less vulnerable overall to predatory fishes that may use the
23   diversion structures for cover.

5.F.5.3.6   Lamprey

5.F.5.3.6.1   CM1 Water Facilities and Operation

26   Lamprey have been observed in fish salvage operations at both the SWP and CVP fish salvage
27   facilities. Because of the difficulty in distinguishing between juvenile Pacific lamprey and river
28   lamprey, salvage data do not differentiate between the two species. Approximately 79% of lamprey
29   salvage between 1993 and 2004 at state and federal facilities occurred during January and February
30   (Appendix 5.B, *Entrainment*). Previous diet studies (Stevens 1966; Nobriga and Feyrer 2007) did not
31   find a single Pacific or river lamprey in the gut of striped bass, largemouth bass, or Sacramento
32   pikeminnow, despite examining thousands of predator guts (9,197 striped bass, 320 largemouth
33   bass, and 322 pikeminnow combined in the two studies). However, the sampling periods of these
34   studies (Stevens 1966: February–November; Nobriga and Feyrer 2007: March–October) did not
35   generally overlap peak lamprey migration periods. Therefore, it is reasonable to assume that
36   predation of lamprey occurs in the Delta, although there is low certainty of the effect that predation
37   has on the species.

38   No studies have been performed to assess the vulnerability of lamprey to predation in the CCF as a
39   consequence of fish salvage operations. Reduced exports from the south Delta will reduce the total
40   number of lamprey entrained at the export facilities, but the proportion of entrained lamprey lost to
41   predation is expected to remain the same under CM1. Lamprey are expected to experience increased

1 predation in the Sacramento River due to the construction of the north Delta export facilities,
2 although the certainty is very low.

5.F.5.3.6.2   Habitat Restoration (CM2, CM4, CM5, CM6, and CM7)

4 Although there is high uncertainty regarding juvenile lamprey (macropthalmia) behavior and
5 habitat requirements in the Delta (U.S. Fish and Wildlife Service 2010), lamprey macropthalmia
6 likely use the Delta primarily as a migration corridor, as evidenced by low catches in beach seines in
7 back sloughs and higher catches in beach seines in mainstem sampling (U.S. Fish and Wildlife
8 Service unpublished data). Only a small proportion of the proposed habitat restoration will be
9 located along major migration corridors, such as the mainstem Sacramento and San Joaquin Rivers,
10 in the West and South Delta ROAs. Therefore, lamprey are presumed not to spend large amounts of
11 time in restored tidal marsh or floodplain habitat. Assuming tidal marsh and floodplain restoration
12 sites will be designed properly to avoid simply creating new habitat for nonnative predators, habitat
13 restoration will result in a small reduction in exposure of lamprey macropthalmia to predators using
14 this habitat, and therefore, a small benefit to lamprey macropthalmia, with low certainty regarding
15 this conclusion. If restored habitats are recolonized by IAV, the benefit of habitat restoration for
16 lamprey in terms of predation may be reduced because of the increased presence of piscivorous
17 largemouth bass.

5.F.5.3.6.3   CM13 Invasive Aquatic Vegetation Control

19 As noted above, lamprey appear to use the Delta primarily as a migration corridor. IAV removal
20 along main migration corridors could have some benefits similar to those assumed for juvenile
21 Chinook salmon by reducing local abundances of centrarchids. However, there is high uncertainty
22 regarding microhabitat use by migrating lamprey and their exposure to predators associated with
23 IAV.

5.F.5.3.6.4   CM15 Localized Reduction of Predatory Fishes

25 It is reasonable to assume that predation of lamprey could occur in the Delta, although there is low
26 certainty of the effect that predation has on the species. Known fish predators of lamprey include
27 white sturgeon, pikeminnow, sculpins, logperch, and channel catfish. Predation of lamprey has yet to
28 be identified as an issue of concern for the species. For this analysis, it is assumed that this predation
29 rate during the months when lamprey are in the Delta is similar to that of Chinook salmon. A
30 potential risk of localized predator removal is incidental bycatch of lamprey by practices such as
31 electrofishing.

5.F.5.3.6.5   CM16 Nonphysical Fish Barriers

33 Effects on lamprey species from predation associated with the construction of nonphysical barriers
34 are unknown. River and Pacific lamprey both are known to inhabit reaches of the Sacramento and
35 San Joaquin River basins upstream of the Delta, so they will encounter the nonphysical barriers at
36 Georgiana Slough and the head of Old River. The nonphysical barriers are likely to attract
37 piscivorous predators hiding among the physical structures of the barrier. Unlike salmon, lamprey
38 are not deterred by the sounds and lights of the barrier, and therefore are not deterred from
39 entering areas of the Delta associated with high predation.

1   ### 5.F.5.3.6.6   CM21 Nonproject Diversions

2   The extent to which lamprey are entrained in unscreened nonproject diversions (e.g., small
3   agricultural diversions) along with the benefits and risks relative to entrainment associated with
4   this conservation measure, has been discussed in Appendix 5.B, *Entrainment*.

5   The predation-related effects relate to the cover provided by the intake structures. Additional
6   structures for screening could attract predatory fish, while consolidation and removal of small
7   diversions could reduce cover. The magnitude of effect would depend in part on the spatial overlap
8   of nonproject diversions and lamprey.

9   # 5.F.5.4   Uncertainties and Research Needs

10   ## 5.F.5.4.1   Uncertainties

11   There is currently a high degree of uncertainty regarding the role of predation on covered fish
12   species populations and the feasibility of reducing predatory fishes. We have limited understanding
13   of the dynamics and importance of predation and competition for covered fish species in the Delta.
14   Designating feasible and effective predator removal methods is challenging, especially in an open
15   system such as the Delta. Some potential reductions may have secondary impacts. Finally, some
16   actions may not be acceptable for social, legal, or policy reasons. Given these uncertainties and
17   constraints, CM15 will initially be implemented as an experimental pilot program and a series of
18   connected research actions.

19   Key uncertainties for developing and evaluating a predator reduction program include the following.

20   ● Under what circumstances and to what degree does predation limit the productivity of covered
21   fish species?

22   ● Which predator species and life stages have the greatest potential impact on covered fish
23   species?

24   ● What habitat factors facilitate predation in the Delta, and how can those impacts be mitigated?

25   ● How should hotspots for localized predator reduction and/or habitat treatment be prioritized?

26   ● What are the best predator reduction techniques? Which methods are feasible, most effective,
27   and best minimize potential impacts on covered species?

28   ● What are the effects of localized predator reduction measures on predator fish and covered fish
29   species (e.g., increased survival)?

30   ● How can predation of covered fish species be detected and measured?

31   These issues are considered in more detail in the following sections for individual conservation
32   measures and covered species.

33   ### 5.F.5.4.1.1   CM1 Water Facilities and Operation

34   Despite a good understanding of what flow levels entrain salmon into the central Delta and to what
35   extent north Delta diversions affect flow patterns, there is still uncertainty regarding overall effects
36   of the new diversions on predation. Uncertainty exists relative to:

37   ● The degree to which predators will aggregate at north Delta intakes.

1   ● The magnitude of losses due to predation at these facilities.

2   ● The amount of predation losses in the central Delta and any changes due to reduced flow
3   downstream of the new north Delta intakes, which could affect movement of juvenile salmonids.

4   ● Estimates of predation and mortality at the south Delta facilities (Gingras 1997; Clark et al.
5   2009; Castillo et al. in press). These estimates often are based on studies of tagged hatchery
6   juvenile salmonids, which may be more vulnerable to predation than wild fish. For delta smelt,
7   high temperatures or experimental conditions at time or location of release may also be factors
8   in overall losses.

9   ### 5.F.5.4.1.2   Habitat Restoration (CM2, CM4, CM5, CM6, and CM7)

10   Uncertainties associated with habitat restoration activities revolve around the extent that habitat
11   restoration activities create predator habitat or encourage predator concentration in areas used by
12   covered fish species. The uncertainty regarding a beneficial outcome is high because data do not
13   exist to estimate the fraction of salmonid fishes that are expected to be lost to predators as a result
14   of changing flow or habitat conditions. The lack of data on how different bypass flows would affect
15   shallow-water habitat, travel time, and flow splits adds to the uncertainty.

16   ### 5.F.5.4.1.3   CM13 Invasive Aquatic Vegetation Control

17   While removal of IAV stands has a high likelihood of locally reducing opportunities for predation by
18   removing habitat favored by largemouth bass, it is unclear whether control efforts would be at a
19   sufficient scale to increase turbidity, which provides cover for smelt (Bennett 2005).

20   ### 5.F.5.4.1.4   CM15 Localized Reduction of Predatory Fishes

21   The extent that predator reduction in the Delta can improve survival of covered fish species is
22   unknown relative to existing biological conditions in the Delta. Uncertainties exist regarding both
23   (1) the effectiveness of predator removal and (2) the response by predator and prey populations.

24   Actions to remove predators have a high degree of uncertainty. Removal efforts may not capture a
25   large enough fraction of the local predator population to sufficiently improve survival rates of
26   covered fish species. Capture success is likely to vary depending on predator size, species, and local
27   habitat conditions. The longevity of these reductions efforts is uncertain because predators are
28   likely to move back into the area and some species, like striped bass, are highly mobile. There is a
29   lack of strong evidence on the long-term benefits of predator removal. Examples from predator
30   control efforts elsewhere, such as the Columbia River (Porter 2010) and Colorado River (Mueller
31   2005), suggest that efforts must be sustained to achieve any benefits.

32   Another significant area of uncertainty regards the response of fish populations to predator
33   reduction. The untested hypothesis of a control program is that predation by striped bass and
34   largemouth bass regulates populations of salmon, steelhead, and smelt and that other predators play
35   a minimal role. Estimates of predation pressure are variable and rough because of uncertainties
36   regarding rates of predator-prey encounters, abundance of predators and prey, and other life
37   history factors that affect capture and consumption (e.g., size and structure of local predator
38   population, bioenergetics).

39   Uncertainty about expected outcomes is high because data are lacking or limited to estimate the
40   fractional increase in covered fish populations resulting from predator reduction actions such as

1   focused predator removal and structure removal or modification. The magnitude of the prey species'
2   response to a predator reduction program is difficult to predict. Models suggest that predators could
3   affect prey numbers (e.g., Lindley and Mohr 2003), but these estimates are not necessarily proven.
4   Striped bass and largemouth bass are generalist predators, and predation pressure on a single prey
5   species may not be high. Thus, the magnitude of the prey species response to reduced predator
6   population size is difficult to predict. Removal of predators could trigger a compensatory response
7   by other predators or by more favored prey species such as threadfin shad, juvenile striped bass,
8   and inland silverside (*Menidia beryllina*). Silversides may compete with delta smelt for copepod prey
9   and may prey on eggs or larvae (Bennett and Moyle 1996).

10   Assumptions regarding manipulation, alteration, and management of predator/prey interactions are
11   uncertain. Therefore, conservation measures that rely on control of predator species might be
12   regarded with uncertainty until proven otherwise.

5.F.5.4.1.5   CM16 Nonphysical Fish Barriers

14   The effectiveness of nonphysical barriers and their interaction with predators is based on limited
15   testing; thus, outcomes for salmonids remain uncertain.

16   Uncertainties associated with nonphysical barriers and other fish population factors revolve around
17   the degree to which these activities create predator habitat, encourage predator concentrations in
18   localized areas occupied by covered fish species, or influence their migration patterns through or in
19   the Delta.

20   Tools such as the DPM, which uses extensive datasets on salmon survival through various Delta
21   migration routes, could be improved or modified to better quantify the effects of predation at
22   nonphysical barriers. Although constrained to an analysis of the effects on salmon, the DPM could
23   add a barriers component or a submodel could be presented as a stand-alone. The baseline
24   condition would be the number of salmon that would die without the barrier in place because they
25   were routed down Georgiana Slough; the contrast is the number that would die with the barrier in
26   place.

5.F.5.4.1.6   CM21 Nonproject Diversions

28   Two studies, prompted by indications that some screens increased predation rates on juvenile
29   Chinook salmon by providing holding areas for predatory fish, were found to be inconclusive (Moyle
30   and Israel 2005). While some screens may be detrimental because of predation on fish species of
31   concern, the effect of individual diversions on these species is likely highly variable, depending on
32   size, location, type (retractable of not retractable), and timing of diversion (seasonal use). Whether
33   there are detrimental effects of screening, including increased predation on species of concern, there
34   simply is not enough information currently available to support a conclusion. Therefore, there is
35   considerable uncertainty regarding the effect of nonproject diversion screening and
36   decommissioning on predation rates on covered fish species.

5.F.5.4.1.7   Fish Species

Delta Smelt and Longfin Smelt

39   Very limited quantitative information is available regarding the current magnitude of smelt loss to
40   predation. The primary intent of localized predator reduction measures under CM15 is to improve

1 migration survival of salmonids. Delta smelt may experience minor, limited ancillary benefits
2 resulting from CM15 actions, especially if they are readily present in identified predator hotspots
3 during periods of localized predator removal treatments. However, it is expected that the effect of
4 local predator reduction efforts generally would provide a minor to negligible benefit to the overall
5 delta smelt population. The benefits for longfin smelt would be even lower, since longfin smelt
6 occupy a smaller area in the Delta.

7   Localized predator reduction measures would reduce predation locally but would not have a
8 discernible effect on the overall populations of striped bass. As striped bass are mobile predators,
9 these efforts would provide some minor benefit, but these benefits would not be expected to be of
10 the same level as in the immediate area of removal.

11 The estimated number of delta smelt lost to predation mentioned above may not reflect current
12 consumption rates, as delta smelt are currently less common than they were when the studies upon
13 which the estimate was based were performed. In addition, Nobriga and Feyrer (2007) did not
14 observe littoral predators consuming any delta smelt. Whether the removal efforts described above
15 produce year-over-year cumulative reductions in overall striped bass abundance will depend on any
16 compensation response in the striped bass population. However, the number of striped bass
17 removed represents only a small fraction of the total number of striped bass, and therefore the
18 removal program may not actually have a discernible effect on smelt numbers.

19 A minor uncertainty was raised earlier regarding the potential for community-level changes due to
20 indirect effects. Would reducing local abundances of predators like striped bass and largemouth
21 bass results in predatory releases of other smaller piscivorous fish like silversides? Such a response
22 could result in a situation where total predation loss of covered fish by striped bass and largemouth
23 bass is reduced, but compensated for by other piscivorous fishes. However, given the localized
24 nature of CM15 implementation, not enough predatory fish would be removed to affect the overall
25 predator populations, and therefore community-level effects would not occur.

26 **Chinook Salmon and Steelhead**

27 Juvenile Chinook salmon are expected to inhabit restored channel margin habitat located along the
28 Sacramento River as resting and foraging areas during downstream migration. Many of the covered
29 fish, such as juvenile Chinook salmon, steelhead, splittail, and sturgeon, use shallow-water habitat
30 for juvenile rearing and foraging. Shallow-water areas also attract and provide habitat for a variety
31 of native and nonnative predatory fish, including striped bass, largemouth bass, bluegill, sunfish,
32 Sacramento pikeminnow, white catfish, and others (Brown 2003; Nobriga and Feyrer 2007). How
33 created shallow-water habitat develops can affect to what extent different fish species use these
34 areas. For instance, shallow Delta habitat dominated by *Egeria* appears to provide mainly rearing
35 habitat for centrarchid and other nonnative fish species potentially at the expense of native fishes
36 (Brown 2003; Feyrer and Healey 2003; Grimaldo et al. 2004; Nobriga et al. 2005; Brown and
37 Michniuk 2007). Grimaldo and coauthors (2000) reported high rates of predation mortality for
38 tethered juvenile Chinook salmon in shallow-water habitats both with IAV (predation rate 95%) and
39 without vegetation (79% predation rate). In addition, it was thought that at certain pikeminnow
40 hotspots a removal rate of 10 to 20% could reduce their predation on juvenile salmonids by 50%
41 (Porter 2010).

42 There are no reliable abundance estimates for steelhead, and very little research has looked at
43 juvenile steelhead vulnerability to predation. As a result, many of these gaps in knowledge are filled
44 using Chinook salmon as a model for steelhead. Although Chinook salmon and steelhead juveniles

1   are similar in many aspects, using predation rates on Chinook salmon juveniles as a model for
2   steelhead is largely an unproven method.

3   Uncertainty also exists regarding the effect that restored shallow-water habitat will have on
4   steelhead populations. Colonization of the restored aquatic habitat by nonnative invasive
5   submerged aquatic plants as well as colonization by predatory fish such as striped bass, largemouth
6   bass, pikeminnow, and others may reduce estimated benefits. Although increased access to
7   intertidal and subtidal habitat in the western Delta has been identified as a net benefit to steelhead,
8   there is uncertainty associated with the quantitative magnitude of net benefits associated with the
9   design, habitat suitability, food production, and resulting increases in juvenile growth rates and
10 survival associated with expansion of channel margin aquatic habitat in the western Delta (Brown
11 2003).

12 As described for smelt, the potential risk of a compensatory response is unlikely, because not
13 enough predatory fish would be removed to affect the overall predator populations.

Sacramento Splittail

15 The extent of predation on splittail by nonnative predators is unknown. As discussed above, it is
16 reasonable to suspect predation of splittail does occur in the Delta, but there is low certainty of its
17 importance to the species. Several Plan conservation measures have the potential to affect predation
18 on splittail, including habitat restoration, changes in lower Sacramento River flow, and north Delta
19 intake structures.

20 Anticipated flow reductions may result in little change on predation on juvenile splittail in drier
21 years but could result in a substantial increase in predation in wetter years. The north Delta intakes
22 will provide new habitat for piscivorous fish such as striped bass, resulting in increased predation
23 on juveniles. The increases could be substantial; however, this conclusion is highly uncertain
24 because the actual predation rates by striped bass and other Delta piscivores on splittail are
25 unknown. Overall, the conservation measures to control predators and removal of IAV could result
26 in minor reductions in predation with respect to predation on splittail, but the magnitude of effects
27 is uncertain.

Green and White Sturgeon

29 There are no reliable abundance estimates for green or white sturgeon in the Delta. The predation
30 rate on juvenile sturgeon is largely uncertain, but it is probably low because of their exterior armor
31 and large size even as juveniles.

5.F.5.4.2   Research Needs

33 Understanding of predator-prey interactions in the Delta and the elements key to the relationship
34 needs to be improved. Even if predator reduction at hotspots is shown to be effective, it will be
35 necessary to evaluate the effect of such control at the scale of the estuary in order to determine
36 whether predator reduction is beneficial to specific fish populations.

37 In addition, even if the exact predation rate on covered fish species is known, knowing total
38 mortality rates for covered fish species and their population's compensatory responses is necessary
39 to put the predation rate into any kind of meaningful context. Therefore, research is needed to
40 establish the relevance of predation on covered fish species population dynamics.

1   Tools such as the DPM, which uses extensive datasets on salmon survival through various Delta
2   migration routes, could be improved or modified to better quantify the effects of predation at
3   localized hotspots, physical and nonphysical barriers, and habitat restoration sites. Although
4   constrained to an analysis of the effects on salmon, the DPM might add components, or submodel
5   presented as a stand-alone, addressing localized predator reduction, barriers, or restoration actions.

6   In addition, more studies similar to the before-after-control-impact design used by Cavallo and
7   coauthors (2012) are needed and could be focused on currently known local hotspots for predation,
8   such as the scour hole at the head of Old River. These types of studies would provide critical
9   information regarding the success of predator reduction activities, especially those related to
10   localized predator reduction. A similar type study could be considered for the CCF to determine
11   whether predator reduction in the forebay does in fact reduce predation loss there.

12   A list of research needs identified thus far are listed in Table 5.F.6-14.

13   **Table 5.F.6-14. Key Uncertainties and Potential Research Actions for Localized Predator Removal**

Key Uncertainty	Potential Research Actions
Under what circumstances and to what degree does predation limit the productivity of covered fish species?	• Evaluate predation effect on productivity of covered fish species using Life-cycle simulation models and bioenergetics modeling.
Which predator species and life stages have the greatest potential impact on covered fish species?	• Determine whether large predators that are comparatively easy to target for reduction are the key predators of some or many covered fishes. • Evaluate predation losses with bioenergetics models and life-cycle models for target species (by life stage). • Conduct site-specific monitoring of predator abundance (by species and life stage) during periods when covered fish species are present (particularly juvenile salmonids). • Conduct site-specific diet composition of predators (at finer resolution than simply "fish"). • Use DNA analysis of predator stomach contents to identify prey species. • Refine bioenergetics modeling of consumption rates with site-specific monitoring data (Loboschefsky et al. 2012).
What habitat factors facilitate predation in the Delta, and how can those impacts be mitigated?	• Identify habitat factors, in addition to those already known (i.e., large water diversions, trapezoidal channels, clear-water conditions, warmer water temperatures, or low-flow conditions). • For known hotspots, establish a habitat suitability approach to identify specific physical features and hydrodynamic conditions that facilitate elevated predation loss.

Key Uncertainty	Potential Research Actions
How should hotspots for localized predator reduction and/or habitat treatment be prioritized?	• Document the extent and locations of predator hotspots within the Delta, and evaluate relative intensity of predation and feasibility of treatment. • Use a habitat suitability approach at known hotspots to identify specific physical features and hydrodynamic conditions that facilitate elevated predation loss. • Monitor predator distribution and abundance at the north Delta intakes to refine preliminary estimates of potential predation loss. • Determine the extent of predator aggression at nonproject barriers before and after installation of the barrier and their effect on migration success of covered fish species. • Evaluate potential attraction of predator to nonphysical barriers (e.g., type of predators, number of predators, proximity of predators to barrier structure, etc.). • Continue with tagging studies to identify areas that facilitate intense predation (e.g., Bowen et al. 2009; Vogel 2011).
What are the best predator reduction techniques? Which are feasible, most effective, and best minimize potential impacts on covered species?	• Test and evaluate various reduction techniques with regards to efficacy, logistics, feasibility, cost and benefits, and public acceptance. • Determine if covered fish species are caught as by-catch during predator reduction efforts and assess ways to reduce such by-catch, if necessary.
What are the effects of localized predator reduction measures on predator fish and covered fish species?	• Before and after studies (BACI design) evaluating the distribution and abundance of predators and covered fish species at treatment location and nearby sites. Metrics include abundance, age classes, and distribution of predators such as striped bass, largemouth bass, and other smaller piscivorous fish. • Tagging studies of covered species survival (migrating juvenile salmonids) before and after predator reduction in reaches with and without reduction efforts (Bowen et al. 2009; Vogel 2008, 2011). • Monitor recolonization rates of habitats by predators following reduction treatments to assess longevity of treatment effects.
How can predation of covered fish species be detected and measured?	• Evaluate suitability of predator-naïve hatchery salmonids as surrogates of naturally spawned fish in tagging experiments to estimate predation rates and survival. • Utilize novel methods such as genetic assays to detect delta smelt in gut contents to document and measure consumption by predators (Baerwald et al. manuscript).
How have other conservation measures affected the distribution and intensity of predation in the Plan Area?	• BDCP restoration efforts are expected to create additional habitat for some species of predators along with covered species (e.g., *CM2 Yolo Bypass Fisheries Enhancement*, *CM4 Tidal Natural Communities Restoration*, *CM5 Seasonally Inundated Floodplain Restoration*, *CM6 Channel Margin Enhancement*, and *CM7 Riparian Natural Community Restoration*). Monitoring and potential active adaptive management studies will be developed, if increased predation is suspected or demonstrated in conjunction with habitat restoration or enhancement projects.

1

1 # 5.F.5.5   Conclusions

2 Predation is a natural ecosystem process. In the Delta, however, there is considerable uncertainty
3 and lack of understanding as to what constitutes a balanced predator-prey relationship.
4 Nevertheless, there are certain situations regarding fish predation in the Delta that are considered
5 important enough to pursue through the conservation strategy. These include:

6 ● Localized predator hotspots.

7 ● Predator attraction to new structures (e.g., new diversions, nonphysical barriers).

8 ● Predator attraction to restored habitat sites.

9 ● The significance of IAV as predator habitat.

10 ● The attraction of predators to the numerous, relatively small nonproject (agricultural)
11   diversions in the Delta.

12 **Implementation *CM1 Water Facilities and Operation* would decrease predation on covered fish at**
13 **the south Delta facilities. Increased predation will likely occur at the north Delta intake facility,**
14 **although the extent of the increase is uncertain.**

15 At the south Delta CVP and SWP facilities, losses attributed to predation are an estimated 75% for
16 salmonids in the SWP's CCF, 15% for salmonids at the CVP facilities, and more than 90% for delta
17 smelt at CCF. Once the north Delta facility is operating, reduced pumping at the south Delta facilities
18 will result in substantially reduced entrainment and thus reduced predation of covered fish species
19 at these facilities.

20 The north Delta export facilities on the banks of the Sacramento River likely will attract piscivorous
21 fish around the intake structures. Predation losses at the intakes were estimated using striped bass
22 bioenergetics modeling of salmon and splittail consumption, and a fixed 5% per intake assumed loss
23 of Chinook salmon smolts migrating past the facilities. While bioenergetics modeling predicted high
24 numbers of juvenile Chinook consumed (tens of thousands), the population level effect is minimal
25 (less than 1% of the annual Sacramento Valley production). The bioenergetics model likely
26 overestimates predation of juvenile salmon and splittail because of simplified model assumptions,
27 further suggesting that potential predation losses at the north Delta would be low.

28 The fixed 5% per intake loss assumption provides an upper bound of estimated losses at the north
29 Delta diversion. Of the Sacramento Basin population of Chinook salmon smolts that reach the Delta,
30 an estimated 3 to 10% (depending on the run) would migrate via the Yolo Bypass and would thus
31 avoid exposure to the north Delta intakes. An estimated 12.0 to 12.8% of the migrating smolt
32 population is assumed lost to predation, impingement, or injury as smolt emigrate past the three
33 north Delta diversion intakes. This loss assumption, based on the GCID diversion, likely
34 overestimates the mortality rates because the north Delta diversion design and siting are
35 considerably different.

36 These two methods provide a hypothetical range of potential mortality at the north Delta diversion,
37 from less than 1% to 12.8%, with uncertainties associated with each estimate. It should be noted
38 that the biological goals and objectives for salmonids (WRCS1, SRCS1, FRCS1, and STHD1) contain
39 survival rate targets in the new north Delta intakes reach (0.25-mile upstream of the upstream-most
40 intake to 0.25-mile downstream of the downstream-most intake) to 95% or more of the existing
41 survival rate in this reach. The reduction in survival of up to 5% below the existing survival rate will

1   be cumulative across all screens, and would not allow high levels of mortality at the new intakes.
2   The adaptive management program provides a mechanism for making adjustments to avoid or
3   minimize this effect. In addition, localized predator reduction (CM15) could provide a small
4   beneficial effect.

5   **Some of the benefits associated with implementation of habitat restoration measures (CM2, CM4,**
6   **CM5, CM6, and CM7) could be offset by an increase in predation by largemouth bass and**
7   **centrarchid fishes if restored areas are colonized by invasive aquatic vegetation;** *CM13 Invasive*
8   *Aquatic Vegetation Control* **and** *CM15 Localized Reduction of Predatory Fishes* **should minimize**
9   **this effect.**

10   If restored habitats become colonized by IAV, they could provide potential habitat for predatory
11   species. As such, predation risks would increase as largemouth bass become more prevalent in those
12   areas. Fish predators use seasonal wetlands, although warmwater species such as centrarchids
13   typically spawn later in the year when covered fish have already started to emigrate. Habitat design
14   and maintenance to discourage use of the restored areas, including removal of IAV, should minimize
15   this effect. Additionally, these restored areas may be targeted for predator removal during key
16   occurrence of covered species in these areas, which may also reduce this effect, although outcomes
17   of localized predator removal are uncertain.

18   *CM15 Localized Reduction of Predatory Fishes* **would reduce predation on covered fish species for**
19   **short periods in these areas, but outcomes are uncertain at the population scale.**

20   Predatory fishes such as striped bass and largemouth bass prey on covered fish species and can be
21   locally abundant at predation hotspots. Adult striped bass are pelagic predators that often
22   congregate near screened diversions, underwater structures, and salvage release sites to feed on
23   concentrations of small fish, especially salmon. Striped bass are a major cause of mortality of
24   juvenile salmon and steelhead near the SWP south Delta diversions (Clark et al. 2009). Largemouth
25   bass are nearshore predators associated with stands of IAV.

26   Targeted predator removal at hotspots, such as the north Delta diversion, would reduce local
27   predator abundance, thus reducing localized predation mortality of covered fish species. Predator
28   hotspots include submerged structures, scour holes, riprap, and pilings. Removal methods will
29   include electrofishing, gill netting, seining, and hook and line. Predator removal measures will be
30   highly localized and thus they would not appreciably decrease Delta-wide abundances of predatory
31   fish. Additionally, intensive removal efforts inadvertently could result in bycatch and take of covered
32   species in localized areas.

33   At the local scale, the benefits of targeted predator removal are likely to be localized spatially and of
34   short duration unless efforts are maintained over a long period of time. These benefits are highly
35   uncertain, as the long-term feasibility and effectiveness of localized predator reduction measures
36   are not known. Other control programs suggest that removal of predators even at a localized scale
37   will be difficult to achieve and maintain without a substantial level of effort. Highly mobile predators
38   like striped bass can rapidly recolonize targeted areas within a matter of days, implying that
39   predator removal will need to be conducted at frequent intervals when covered species are
40   migrating.

41   At the population scale, the overall benefit for covered fishes is uncertain because local predator
42   reduction efforts may not capture sufficient predators to appreciably reduce mortality of covered
43   fishes. Also, there are uncertainties regarding causal relationships between Delta predators and

1 prey that make it difficult to predict the role of piscivorous fish in affecting the size of fish
2 populations Delta-wide (Durand 2008; Nobriga pers. comm.). A pilot program and research actions
3 proposed under *CM15 Localized Reduction of Predatory Fishes* will help address knowledge gaps
4 about effectiveness of predator removal techniques and the relative impact of top-down predation
5 on the population dynamics of covered fish species in the Delta.

6 ***CM16 Nonphysical Fish Barriers* could reduce fish predation by deterring covered fish from**
7 **predation hotspots. The underwater infrastructure may attract predatory fish, but predator**
8 **removal could help reduce predation risk.**

9 Nonphysical barriers at the head of Old River and at Georgiana Slough are designed to deter juvenile
10 salmonids from entering certain reaches of the Delta associated with poor survival. These barriers
11 operate by using strobe lights and speakers to deter juvenile fish, with a bubble curtain designed to
12 contain the noise and form a wall of sound. Salmon, steelhead, and splittail are expected to be
13 effectively deterred. Sturgeon and lamprey are not expected to be deterred by the presence of the
14 barriers. Delta smelt may be deterred to some extent, although weak swimming as young juveniles
15 decreases their ability to avoid the barriers. Longfin smelt are distributed too far west in the Delta to
16 encounter the nonphysical barriers. There may be a slight risk of predation related to the
17 underwater structures associated with nonphysical barriers that may attract fish predators. If
18 needed, targeted predator reduction measures (CM15) would be implemented in these areas.

19 **Consolidation and screening of nonproject diversions (*CM21 Nonproject Diversions*) in the Delta**
20 **will have an unknown effect on fish predation.**

21 Much of the effect will depend on where in the Delta these nonproject diversions are, how and when
22 they are operated, the size and extent of submerged structure associated with them, and how they
23 will be modified. Installation of fish screens and other structures intended to reduce entrainment
24 losses of covered fish actually may attract additional predators and increase localized predation
25 risks. Consolidation would reduce the number of structures providing cover.

26 5.F.6   Invasive Mollusks

27 5.F.6.1   Ecological Effect Pathways

28 5.F.6.1.1   Overbite Clam (*Potamocorbula amurensis*)

29 *Potamocorbula* was introduced to San Francisco Bay in 1986 from Asia, likely as larvae transported
30 in ballast water, and spread rapidly throughout the estuary (Carlton et al. 1990; Alpine and Cloern
31 1992). It is hypothesized that invasion was facilitated by a major flood in 1986 that wiped out the
32 benthic community in the Suisun Bay area, permitting the establishment of *Potamocorbula*. A
33 subsequent drought from 1987 to 1992 provided low-flow, high- salinity conditions that favored its
34 spread. A decline in fall outflow following the drought led to increased fall salinity in the western
35 Delta and Suisun Bay, facilitating further expansion (Winder and Jassby 2010).

36 *Potamocorbula* now dominates the entire brackish transition zone of the estuary, and its grazing
37 influence extends well into the eastern Delta due to mixing from tidal action (Durand 2008). It is
38 abundant in the Carquinez Strait, San Pablo Bay, Suisun Bay, Grizzly Bay, and the western Delta
39 (Thompson 2000; California Department of Water Resources 2010b, 2010c). Densities in Suisun

1   Marsh vary among the sloughs in association with salinity (O'Rear and Moyle 2008, 2009). Peak
2   densities occur in summer or fall. In 2008 and 2009, densities approached or exceeded 29,000 clams
3   per square meter (California Department of Water Resources 2010b, 2010c). Abundance of
4   *Potamocorbula* declines each winter, likely due to increased predation pressure by diving birds and
5   high freshwater outflows (Poulton et al. 2002, 2004).

6   The invasion of *Potamocorbula* has dramatically altered the benthic and planktonic community of
7   the Delta (Kimmerer et al. 1994; Peterson and Vayssieres 2010; Baxter et al. 2010). Werner and
8   Hollibaugh (1993) calculated that at typical densities in the northern bay, *Potamocorbula* is capable
9   of filtering phytoplankton from the entire water column more than once per day over Delta channels
10 and almost 13 times per day over shallow areas. This filtration rate exceeds the specific growth rate
11 of phytoplankton, and as a result phytoplankton biomass in Suisun Bay dropped from a summer
12 average of >20 mg chl a m^{-3} before *Potamocorbula* invasion to <2 mg chl a m^{-3} post- invasion (Alpine
13 and Cloern 1992; Jassby et al. 2002). The zone of depleted chlorophyll has extended well beyond the
14 geographic distribution of the clam (Pereira et al. 1992) because chlorophyll produced in Suisun Bay
15 is no longer available to be delivered to upstream locations through tidal mixing (Kimmerer and
16 Orsi 1996; Jassby et al. 2002). Much of the decline in summer phytoplankton has been in diatom
17 biomass, and the linkage between this decline and the introduction of *Potamocorbula* is strong, with
18 minor influences of freshwater flow and temperature (Jassby et al. 2002; Kimmerer 2005).

19 The decline in phytoplankton biomass has been correlated with long-term declines of copepods and
20 mysid shrimp (Kimmerer et al. 1994; Kimmerer and Orsi 1996; Orsi and Mecum 1996). The decline
21 in these food resources has been linked to reductions of some planktivorous fishes (Kimmerer 2002;
22 Feyrer et al. 2003; Sommer et al. 2007). *Potamocorbula's* effect on calanoid copepods, a main prey
23 item of delta smelt, is a function of both direct grazing on larval stages (microzooplankton such as
24 copepod nauplii) and the indirect effects of competition for phytoplankton (Kimmerer et al. 1994;
25 Kimmerer and Orsi 1996; Orsi and Mecum 1996). Kimmerer (2008) showed a positive relationship
26 between delta smelt survival from summer to fall and zooplankton biomass in the low salinity zone,
27 consistent with the hypothesis that food is a factor limiting delta smelt populations. Also consistent
28 with the food limitation hypothesis is the decline in the growth rate and mean size of adult delta
29 smelt, which followed the introduction of *Potamocorbula* (Bennett 2005). The sharp reduction in
30 phytoplankton caused major declines in the abundance of many planktonic invertebrates, including
31 copepods (a primary prey item for delta smelt) (Kimmerer et al. 1994; Kimmerer and Orsi 1996;
32 Moyle 2002).

33 A major decline in the native mysid shrimp, *Neomysis mercedis*, was attributed to competition with
34 *Potamocorbula* for phytoplankton, resulting in a lack of food for *Neomysis* (Orsi and Mecum 1996).
35 The decline in mysids resulted in substantial changes in the diet composition of longfin smelt
36 (Feyrer et al. 2003). Longfin smelt annual relative abundance has been linked to Delta outflow (e.g.,
37 Kimmerer et al. 2009) and was lower per unit outflow after *Potamocorbula* became established
38 (Sommer et al. 2007).

39 Documented consumers of *Potamocorbula* include Dungeness crab (*Cancer magister*) (Carlton et al.
40 1990; Stewart et al. 2004), Sacramento splittail (Deng et al. 2007), white sturgeon (Urquhart and
41 Regalado 1991; Kogut 2008), and diving ducks such as surf scoters (*Melanitta perspicillata*) and
42 greater and lesser scaup (*Aythya marila* and *A. affinis*) (White et al. 1989; Urquhart and Regalado
43 1991; Linville et al. 2002). The position of *Potamocorbula* in the sediment makes them more
44 available to predators than the deep-burrowing bivalve that previously dominated the northern

1   estuary (*Macoma petalum*, previously known as *Macoma balthica*). The caloric content of the two
2   bivalves is similar (Richman and Lovvorn 2004).

3   Filter feeders can bioaccumulate contaminants at very high rates, and *Potamocorbula* has been
4   shown to bioaccumulate selenium at very high concentrations in Suisun Bay. Selenium can cause
5   chronic toxicity (especially impaired reproduction) in fish and aquatic birds (Presser and Luoma
6   2010; Ohlendorf 2003; San Francisco Bay Regional Water Quality Control Board 2009). A full
7   analysis of the fate and transport of selenium in the Delta, and the potential for the BDCP to result in
8   increases bioavailability of selenium, especially in Suisun Bay, is included in Appendix 5.D,
9   *Contaminants*. As discussed in Appendix 5.D, it is unlikely that covered activities will result in an
10 increase in selenium bioavailability, and increased amounts are not expected to enter the food chain
11 through the filter feeders.

5.F.6.1.2   Asian Clam, *Corbicula fluminea*

13 The Asian clam, *Corbicula fluminea*, invaded the estuary in the mid-1940s, and is found in fresh and
14 low salinity regions of the Delta. Although *Corbicula* can be quite abundant, it has a more patchy
15 distribution than *Potamocorbula,* and therefore has a more limited impact on phytoplankton
16 abundance (Lucas et al. 2002). In addition, *Corbicula* does not appear to graze directly on
17 zooplankton, so its impact on zooplankton is limited to indirect competitive effects (Durand 2008).

18 Grazing by *Corbicula* is not as efficient as *Potamocorbula* in terms of filtration rates, but *Corbicula*
19 still can quickly filter out shallow water bodies when in sufficient densities. In shallow-water areas
20 such as Franks Tract, dense populations of *Corbicula* collectively can filter the entire water column
21 in less than a day (Lucas et al. 2002). Like *Potamocorbula*, *Corbicula* is thought likely to affect
22 zooplankton populations by reducing the abundance of phytoplankton (Durand 2008), although this
23 link has not been clearly established. Because of its long presence in the estuary it is not possible to
24 analyze the benthic community before and after its introduction or detect its effects on the foodweb
25 (Baxter et al. 2010).

26 Along with *Potamocorbula, Corbicula* provide food for benthic feeding fishes such as sturgeon and
27 splittail, and it is one of the most commonly identified benthic organisms in fish stomachs collected
28 from the Delta (Gleason 1984; Herbold and Moyle 1989). As a filter feeder, *Corbicula* can
29 bioaccumulate contaminants, such as selenium, at relatively high rates, if the contaminants are
30 present (Lee et al. 2006). However, as discussed in Appendix 5.D, *Contaminants*, covered activities
31 will not likely result in conditions that will increase the amount of selenium available to *Corbicula*.

5.F.6.1.3   Zebra Mussels and Quagga Mussels

33 Two species of dreissenid mussels, zebra mussels (*Dreissena polymorpha*) and quagga mussels
34 (*D. bugensis*), are not currently present in the Delta. However, their rapid spread and negative
35 ecological effects, as observed in other ecosystems (Benson et al. 2012; Cohen 2008; Kissman et al.
36 2010), merit evaluation of their invasion potential for the future.

37 Zebra mussels and quagga mussels are among the most significant biological invasions into North
38 America (Benson et al. 2012). Zebra mussels first were documented in California in January 2008 at
39 San Justo Lake, a reservoir in San Benito County (U.S. Geological Survey 2011). Quagga mussels have
40 been found since 2007 in multiple reservoirs in southern California (Orange, Imperial, and San
41 Diego Counties) that receive raw water from the Colorado River (U.S. Geological Survey 2011).

1   Zebra mussels colonize hard substrates, and quagga mussels colonize both hard and soft substrates
2   and colonize deeper water than zebra mussels. These mussels can reach extraordinary densities and
3   are notorious for their biofouling capabilities in water supply pipes, boats, and other submerged
4   structures. Both species are prodigious water filterers that can remove substantial amounts of
5   phytoplankton, microzooplankton, and suspended particulate matter from the water (Kissman et al.
6   2010). Mussels can bioaccumulate contaminants. The potential effects of these species would be
7   similar to those of *Potamocorbula* in those areas where mussels could become established.

8   5.F.6.2   Conceptual Model and Hypotheses

9   5.F.6.2.1   Conceptual Model

10   This section describes the conceptual model that guides the analysis in subsequent sections of
11   potential outcomes of the conservation measures. The model addresses invasive clams and their
12   potential effects on the foodweb supporting covered fish species, discussed in the preceding section
13   on Ecological Pathways. It is based on information in the scientific literature, the draft DRERIP
14   foodweb conceptual model (Durand 2008) and the DRERIP *Potamocorbula* model (Thompson and
15   Parchaso 2010).

16   5.F.6.2.1.1   Physiological Tolerances of *Potamocorbula* and *Corbicula*

17   *Potamocorbula* is a dioecious (sexes are separate), broadcast-spawning bivalve with external
18   fertilization. It grows to around 2 to 3 cm in length. *Potamocorbula* spends most of its 2 to 3 year life
19   in the sediment, spending about 3 weeks in the water column during its larval dispersal phase.
20   *Potamocorbula* reaches maturity at a few months of age. A single female can produce from 45,000 to
21   220,000 eggs. *Potamocorbula* commonly reproduce twice a year, but can reproduce continuously if
22   conditions permit,, and there is some spawning year-round. Juveniles become reproductively active
23   at about 5 mm in length (Parchaso and Thompson 2002), which can occur within 2 months of
24   recruitment. In laboratory studies, the larvae spent 17 to 19 days in the plankton.

25   Physiological tolerances of *Potamocorbula* are summarized in Table 5.F.7-1. Adult *Potamocorbula*
26   can tolerate weeks of exposure to salinities ranging from 0 to 35 ppt, but long-term survival is
27   highest at salinities from 5 to 25 ppt (Nicolini and Penry 2000). All life stages appear to be
28   euryhaline; fertilization occurs in a somewhat narrower range (5 to 25 ppt), but developmental
29   stages between 12-hour ciliated blastula and adult can tolerate 2 to 30 ppt (Nicolini and Penry
30   2000). Additionally, gametes, embryos, and larvae of *Potamocorbula* can tolerate step increases in
31   salinity of at least 10 ppt, although rapid changes appear to reduce larval growth (Nicolini and Penry
32   2000). Successful maintenance and expansion of the distribution of *Potamocorbula* are facilitated by
33   transport of the embryos and larvae with water currents. Recruitment of the species into the
34   northern portions of the estuary, including the reach from San Pablo Bay to the Lower Sacramento
35   River (Peterson and Vayssieres 2010), is dependent on the timing of spring outflow, which can
36   prevent upstream migration even when salinity conditions are favorable. The ability of the clam's
37   larval stage to tolerate a wide range of salinity and relatively large step changes may increase its
38   ability to recruit successfully into estuary habitat (Nicolini and Penry 2000). Peterson and
39   Vayssieres (2010) examined DWR benthic monitoring data over 27 years at four locations in the
40   estuary (San Pablo Bay, Grizzly Bay, Lower Sacramento River, and Old River) and found that benthic
41   assemblage composition varied with salinity and hydrology but was not strongly associated with
42   physical habitat attributes such as substrate.

1   There is also evidence of a strong long-term positive relationship between pH and *Potamocorbula*
2   abundance, and *Potamocorbula's* pelagic larval stage appears to exhibit accelerated rates of
3   calcification in summer when temperature and pH are elevated (Glibert 2010; Glibert et al. 2011).
4   These adaptations may allow *Potamocorbula* to outcompete other species during droughts or under
5   dry conditions (Glibert 2010; Glibert et al. 2011), and when discharge of ammonia and ammonium
6   from wastewater treatment plants results in ammonium toxicity for other species (Ballard et al.
7   2009).

8   **Table 5.F.7-1. Habitat Requirements of Invasive Mollusks**

Habitat Attribute	Present in Delta (Clams)		Not Currently Present in Delta (Dreissenid Mussels)	
	Overbite Clam *Potamocorbula amurensis*	Asian Clam *Corbicula fluminea*	Quagga mussel *Dreissena bugensis*	Zebra mussel *D. polymorpha*
Salinity tolerance	5–25 ppt fertilization 2–30 ppt larvae 5–25 ppt adult optimum ≥0.01–35 ppt adult tolerance (Nicolini and Penry 2000)	<2 ppt larvae; ≤10 ppt adults (Aguirre and Poss 1999)	≤4–6 ppt adults tolerance, less at higher temperatures (Cohen 2008)	≤2–4 ppt at 3–12°C ≤1 ppt at warmer (Mackie and Schloesser 1996)
Temperature	8–23°C in Delta 0–28°C in native distribution (Cohen 2011)	2–30°C (Aguirre and Poss 1999)	4–27°C (Cohen 2008)	6–30°C (Cohen 2008).
pH	Greater densities at higher pH (tested at pH 7.2–8)	pH 5.5–8.3 (Vidal 2002)		pH 7.4–9.4 larvae (Sprung 1993)
Substrate	Mud, sand, peat, and clay substrates. Does not recruit on hard substrates (Baxter et al. 2010)	All types used, but prefer intermediate size (Thorp 2010)	Found on hard substrates and deep, soft sediments (Wilson et al. 2006)	Prefer hard substrates, especially artificial ones (Mackie and Schloesser 1996).
Depth	Found intertidally, but most at subtidal depths (Carlton et al. 1990). Found at depths up to 30 meters	Found at wide range of depths (Thorp 2010); limited by anoxia	Adults found at depths up to 130 m (Mills et al. 1993)	Adults found at depths up to 110 m (Mills et al. 1993)
Dissolved oxygen	High tolerance of hypoxic conditions (McEnnulty 2001)	Relatively intolerant of low DO at high water temperatures (20–30°C) compared to other bivalves (McMahon 1979)	Likely tolerant of hypoxic conditions based on their presence at deep depth (McMahon 1996)	Relatively intolerant of anoxic conditions, but adults can survive for short periods of time
Diet	Bacteria, phytoplankton, microzooplankton (e.g., *copepod nauplii*). Phytoplankton is dominant carbon source (Greene et al. 2011).	Bacteria, phytoplankton. Maximum prey size 20–20 µm (Way et al. 1990)	Phytoplankton, microzooplankton (Kissman et al. 2010)	Phytoplankton, microzooplankton (Kissman et al. 2010)

9

10   *Corbicula* typically is found in habitats with salinities less than 2 ppt, mostly due to the physiological
11   constraints of juveniles (Aguirre and Poss 1999). After consecutive high outflow years *Corbicula* is
12   among the dominant benthic organisms within the Delta and in Suisun Bay (Peterson and Vayssieres

1   2010). Once established, adult clams can withstand salinities of 10 ppt and greater. *Corbicula*
2   currently exist within most freshwater areas in the Delta and river channels east of Suisun Bay
3   (Cohen and Carlton 1995; California Department of Water Resources 2010b). In Suisun Marsh,
4   *Corbicula* occurs in Montezuma Slough upstream of the salinity control gates and in the upper
5   reaches of Suisun Slough in all years. In the central Delta, *Corbicula* achieves high abundance and
6   biomass in Franks Tract and in its surrounding sloughs (Lopez et al. 2006). *Corbicula* is also
7   common in the sloughs surrounding Mildred Island but very sparsely distributed inside of Mildred
8   Island (Lopez et al. 2006). *Corbicula* has been reported by the U.S. Geological Survey (USGS) and
9   DWR in other flooded islands, including Big Break, Liberty Island, and Sherman Island. Peak
10   *Corbicula* densities can exceed 3,000 clams per square meter in the lower Sacramento River (August
11   2008) (California Department of Water Resources 2010b) and about 1,500 in the lower San Joaquin
12   River (October 2009) (California Department of Water Resources 2010c).

13   *Corbicula* can live in all water depths, all substrate types including concrete and peat, and can be
14   found in *Egeria* and tule stands. It can occur in permanently inundated and tidally exposed habitats
15   where *Corbicula* can withstand multiple days of exposure. *Corbicula* can tolerate low pH and has the
16   ability to reduce its metabolic rate by 90% during periods of low food availability (Ortmann and
17   Grieshaber 2003). *Corbicula* also is highly tolerant of turbid conditions (Way et al. 1990), and its
18   ability to exit the sediment during poor water quality conditions and be carried down-current may
19   enhance survival.

20   *Corbicula* is viviparous (produce live young), releasing benthic pediveliger larvae or planktonic
21   veligers that become benthic within 48 hours (Eng 1979). Adult clams are found with mature eggs
22   year around, and they are believed to have two reproductive periods per year, one in spring and the
23   other in fall. Individuals can self- fertilize their eggs (Kraemer and Galloway 1986), allowing single
24   individuals to potentially establish new populations. Juvenile clams become reproductively active
25   around 6 to 10 mm in length (Kraemer and Galloway 1986), which can occur within a few months of
26   recruitment. *Corbicula* is presumed to live 3 to 4 years, although some hypothesize they can live
27   longer.

28   The fluctuation of salinity on different timescales affects adult mortality of invasive clams and
29   annual larval recruitment, helping to determine the extent of *Potamocorbula* and *Corbicula* in the
30   Plan Area (Peterson and Vayssieres 2010). Adult clams are not mobile, but the larval life stage can
31   be transported with currents and become established if conditions are suitable. As noted previously,
32   *Potamocorbula* larvae require salinity greater than 2 ppt to successfully recruit and can tolerate
33   salinity from 2 to 30 ppt (Nicolini and Penry 2000). Conversely, *Corbicula* require salinities less than
34   2 ppt for recruitment, although adults can tolerate salinities up to 10 to 13 ppt. Durand (2008) noted
35   that salinity shifts outside the range of a species' salinity tolerances that occur on timescales smaller
36   than their lifespan, but longer than their ability to tolerate unfavorable conditions, may result in
37   high adult mortality, while shifts that occur over long timescales or very short timescales will result
38   in large, dense populations becoming established. Thus, a long period of high flows may lead to
39   increases in *Corbicula* but limit *Potamocorbula* juvenile success and increase adult mortality because
40   of prolonged exposure to low salinities. However, if an extended period of high flows is followed by
41   a dry year, higher than normal numbers of juvenile *Potamocorbula* may be seen the following year
42   as X2 moves upstream (Durand 2008).

5.F.6.2.1.2 Physiological Tolerances of Mussels

The invasion risk of zebra/quagga mussels depends on salinity, calcium, and alkalinity (pH) (Whittier et al. 2008; Cohen 2008; Claudi and Prescott 2011). Zebra/quagga mussels are predominantly freshwater, but they can tolerate salinity up to 5 ppt (Spidle et al. 1995). North American populations of zebra mussel can tolerate salinity up to 4 ppt (Benson et al. 2012). Other studies suggest limiting values of 2 to 10 ppt to assess zebra mussel distribution (reviewed by Cohen 2008). Quagga mussels are less tolerant of salinity than zebra mussels. Calcium is considered a key limiting factor, required for basic metabolic function as well as shell building (Whittier et al. 2008).

The invasion risk of zebra/quagga mussels in the Delta has been evaluated by CDFW (Cohen 2008) and DWR (Claudi and Prescott 2011). Cohen (2008) used salinity and calcium to evaluate invasion risk at six locations in the Delta (Sacramento River at Isleton, Rock Slough, Old River Intake, CCF, Old River at Tracy Road Bridge, and San Joaquin River at Antioch Ship Channel). Cohen (2008) selected maximum salinities of 6 ppt for zebra mussels and 4 ppt for quagga mussels.

Salinity is typically less than 1 ppt at these locations. A review by Cohen (2008) suggested calcium concentrations of 12 to 28 mg/L as a limiting threshold. Calcium is required for shell calcification of larvae at settlement. Calcium (range 6–33 mg/L), not salinity, appeared to be the limiting factor. Areas in the Delta deemed to have insufficient calcium (<12 mg/L) included Sacramento River at Isleton, Rock Slough, and Old River Intake. Calcium concentrations exceeded 28 mg/L at Old River at Tracy Road Bridge, and San Joaquin River at Antioch Ship Channel. CCF is moderately vulnerable because of intermediate calcium levels.

Claudi and Prescott's (2011) risk assessment focused on the relationship of calcium and alkalinity (Table 5.F.7-2). They hypothesized that pH above 8 may facilitate survival at sites with marginal calcium concentrations, such as Barker Slough, San Joaquin River near Vernalis, and CCF (Claudi and Prescott 2011). This does not account for possible fluctuations in calcium and alkalinity. Given the limited knowledge of survival of dreissenid populations under marginal conditions of calcium and pH, predictions of survival at these locations are uncertain (Claudi and Prescott 2011).

Table 5.F.7-2. Conditions of Calcium and pH Hypothesized to Support Dreissenid Mussels

pH level	Calcium Concentration		
	<12 mg/L	12–15 mg/L	>15 mg/L
<7.3	Unable	Unable	Unable
7.3–7.8	Unable	Potentially able	Potentially Able
>7.8	Unable	Potentially able	Able
Source: Claudi and Prescott 2011.			

5.F.6.2.2 Assumptions

Key assumptions of this conceptual model include the following:

- Salinity distribution limits recruitment and establishment of *Potamocorbula* (require >2 ppt) and *Corbicula* (require <2ppt).

- Grazing by invasive clams contributes to food limitation of planktivores such as delta smelt and longfin smelt.

1 ● Grazing by invasive clams may reduce foodweb benefits to covered fish species from habitat
2   restoration.

5.F.6.3 Potential Effects: Benefits and Risks

5.F.6.3.1 CM1 Water Facilities and Operation

5 Water operations (CM1) that affect salinity gradients could affect the recruitment and distribution of
6 *Potamocorbula* in the western Delta and *Corbicula* in freshwater habitats (Peterson and Vayssieres
7 2010). For example, if the LSZ of X2 moves upstream in the Delta during the *Potamocorbula* larval
8 recruitment period, that could increase opportunities for *Potamocorbula* to recruit further into the
9 central Delta. Conversely, this could reduce available habitat for *Corbicula,* which requires more
10 freshwater conditions (<2 ppt). *Potamocorbula* is more abundant in San Pablo Bay during wet years
11 but more abundant in Grizzly Bay and Suisun Bay in dry years (Peterson and Vayssieres 2010). In
12 general, assemblages of brackish benthic species such as *Potamocorbula* shift downstream in years
13 with high Delta outflow, and upstream during years with low Delta outflow (Peterson and
14 Vayssieres 2010). Wet years in Suisun Bay are characterized by a higher percentage of reproductive
15 individuals, while in dry years a higher percentage occurs in San Pablo Bay (Parchaso and
16 Thompson 2002). The higher rates of reproduction in Suisun Bay in wet years may be linked to
17 increased transport of phytoplankton food resources from upstream Delta reaches.

18 Changes in water operations (CM1) may shift X2 compared with EBC2 by altering the amount of
19 freshwater flows through the West Delta. The effect of water operations on *Potamocorbula*
20 distribution was evaluated by modeling the potential area of habitat suitable for *Potamocorbula*
21 recruitment (area greater than 2 ppt) (Table 5.F.7-3, Table 5.F.7-4, Table 5.F.7-5, Figure 5.F.7-1, and
22 Figure 5.F.7-2). CM1 water operations will be based on the outcome of the decision tree process for
23 fall and spring outflow. There are two potential fall outflow outcomes. The ESO would include the
24 Fall X2 requirement. However, it may be that additional data and analysis obtained before CM1 is
25 constructed could lead to a decision not to implement the Fall X2 actions. In that scenario, fall Delta
26 outflow standards would be operated to meet D-1641 requirements, and CM1 operations would be
27 more similar to Alternative 1A (ALT1_ELT and ALT1_LLT). The methodology used for this analysis is
28 presented in Section 5.F.3.3.

29 The median (50th percentile) annual area of suitable habitat (≥ 2 ppt) for *Potamocorbula*
30 recruitment in the West Delta and Suisun Bay subregions ranged from approximately 94 km^2 (EBC2,
31 EBC2_ELT, and ESO_LLT scenarios) to about 103 km^2 (EBC1), reflecting the absence of the Fall X2
32 water management measure in the EBC1 scenario. Excluding EBC1, average suitable habitat area
33 primarily varied by water-year type and time period, with less difference between scenarios, and
34 ranged from about 78 to 82 km^2 in wet years to about 115 to 118 km^2 in critical years (Table
35 5.F.7-3). There generally was little difference (<5%) in average suitable habitat area between EBC2
36 scenarios and ESO scenarios, with the exception of EBC2 vs. ESO_LLT in wet years (over 4 km^2 more
37 under the latter scenario, or around 6% greater). However, this difference was driven by greater
38 salinity assumed under climate change, because there was little difference when accounting for
39 climate change (EBC2_LLT vs. ESO_LLT).

40 Overall, the results indicated that the ESO generally provided similar *Potamocorbula* recruitment
41 habitat suitability in the West Delta and Suisun Bay subregions compared to the EBC2 scenarios,
42 reflecting the inclusion of the Fall X2 water management measure in CM1 during the main
43 *Potamocorbula* recruitment period. However, if Fall X2 actions are not implemented, Delta salinity

1   conditions under BDCP operations would be similar to conditions modeled as Alternative 1A
2   (ALT1_ELT and ALT1_LLT), which represent a combination of *CM4 Tidal Natural Communities*
3   *Restoration* with water operations that do not include a Fall X2 action. This would facilitate
4   expansion of *Potamocorbula* farther upstream into the Delta during the fall of wet and above normal
5   water-year types. Historically, about 47% of water-year types were classified as wet or above
6   normal.

7   For ESO without Fall X2 (modeled as ALT1_ELT and ALT1_LLT), the area of suitable abiotic habitat
8   for *Potamocorbula* would increase 7 to 9% in wet water-year types compared with the EBC1
9   baseline, but would be little different for all other water-year types. Suitable abiotic habitat for
10   clams would increase in wet and above normal water-year types by about 18 to 28% in early long-
11   term compared with EBC2 baselines (EBC2, EBC2_ELT) and increase 11 to 30% in late long-term.
12   Because Fall X2 requirements apply only to wet and above normal years, there would be no
13   difference in abiotic habitat for *Potamocorbula* between ESO without Fall X2 requirements
14   (ALT1_ELT and ALT1_LLT) and EBC2 baselines in below normal, dry, and critical water-year types.

15   This analysis, however, simplifies the complex situation of invasive clams in the Delta. First, the
16   main period of larval recruitment of *Potamocorbula* varies based on geographic location, occurring
17   nearly year-round in Grizzly Bay, spring to early summer in San Pablo Bay, and predominantly
18   summer and fall near Chipps Island (Thompson and Parchaso 2010). Therefore, periods with more
19   upstream X2 can allow *Potamocorbula* to expand their distribution. Adult *Potamocorbula* would be
20   able to persist at salinities down to 0.1 ppt for some periods of time. Furthermore, natural variation
21   in climatic factors such as drought would facilitate further expansion of *Potamocorbula* eastward
22   irrespective of flow operations under the conservation strategy. Seasonal *Potamocorbula* abundance
23   declines in winter-spring, possibly due to winter outflow conditions or to increased predation by
24   diving birds (Poulton et al. 2002, 2004).

25   Finally, *Corbicula* would be capable of colonizing new habitat that is too fresh for *Potamocorbula*
26   recruitment, such as Cache Slough, East Delta, and South Delta ROAs. *Corbicula* is already present in
27   many of these regions. The effects of *Corbicula* on planktonic food resources may be slightly less
28   than those of *Potamocorbula* because these freshwater clams are not as powerful filter-feeders and
29   they have a more patchy distribution (Lucas et al. 2002).
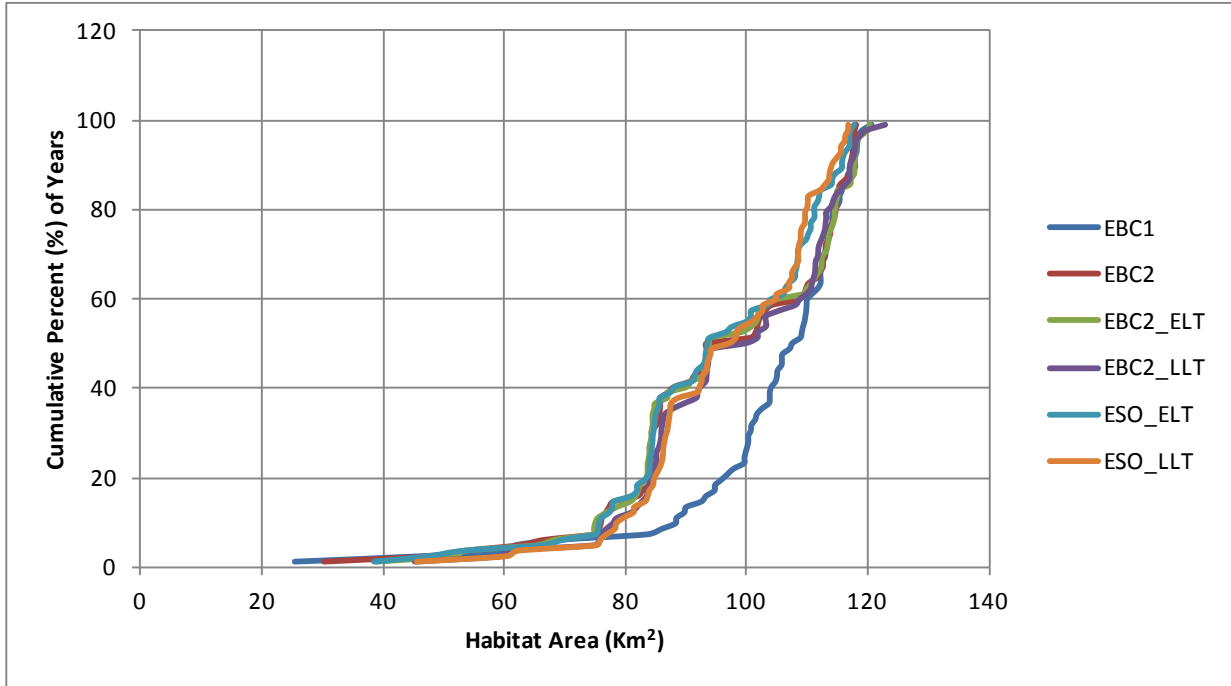
1

2 **Figure 5.F.7-1. Cumulative Percentage of Years (1922–2002) Against Area of Suitable Salinity Habitat**
3 **(≥2 Parts per Thousand) for *Potamocorbula* Recruitment in the Suisun Bay and West Delta Subregions**
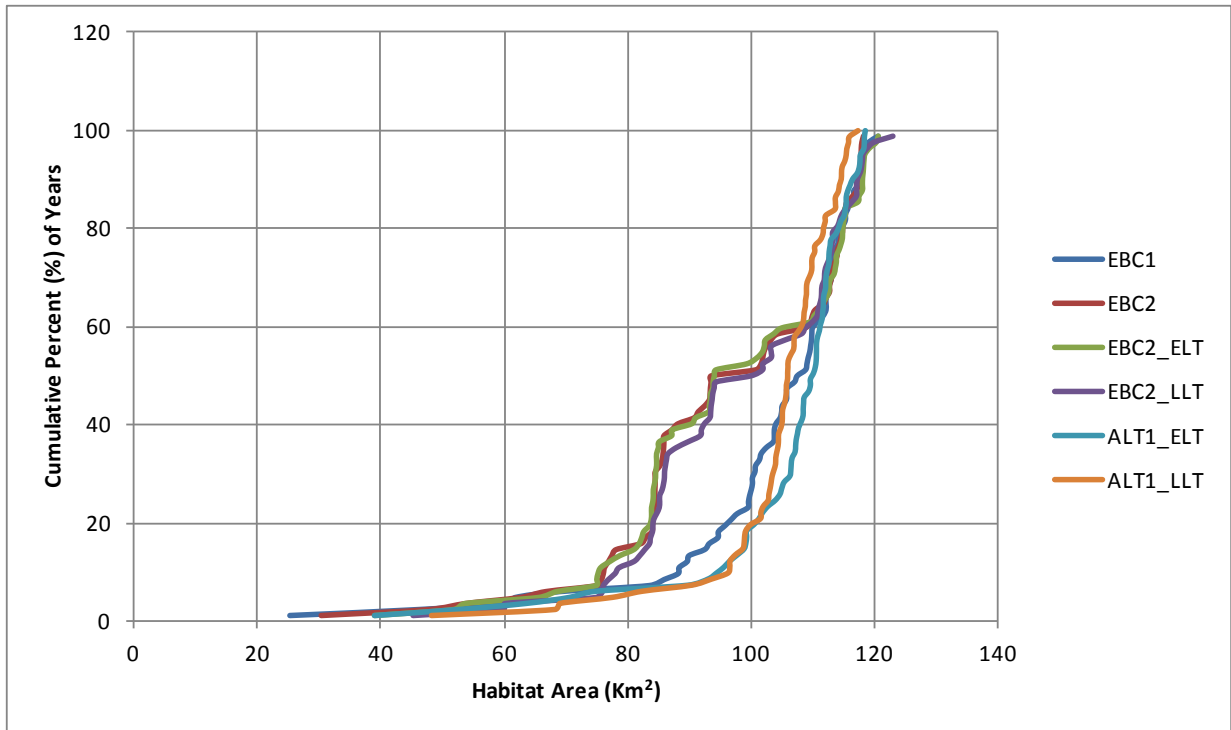
4

5 **Figure 5.F.7-2. Cumulative Percentage of Years (1922–2002) Against Area of Suitable Salinity Habitat**
6 **(≥2 Parts per Thousand) for *Potamocorbula* Recruitment in the Suisun Bay and West Delta Subregions**
7 **under "No Fall X2" Operations (ALT1_ELT and ALT1_LLT)**

1 **Table 5.F.7-3. Average *Potamocorbula* Recruitment Area of Suitable Habitat (km^2) in the Suisun Bay**
2 **and West Delta Subregions by Water-Year Type (with October–December Included in the Previous**
3 **Year Water-Year Classification), by Modeling Scenario**

Water-Year Type	Modeling Scenario (Fall X2 operations implemented?)							
	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT	ALT1_ELT	ALT1_LLT
	No Fall X2	Fall X2 included			Fall X2 included		No Fall X2 Implemented	
All	103.4	96.5	96.7	98.0	95.1	96.6	105.9	104.3
Wet	92.9	77.8	78.9	81.4	78.9	82.2	99.8	101.1
Above Normal	102.7	87.5	86.2	89.5	86.4	89.8	103.6	100.8
Below Normal	103.4	103.7	102.6	104.1	99.4	101.0	104.9	101.3
Dry	109.6	109.5	109.7	109.5	106.8	106.0	110.1	106.9
Critical	117.9	117.3	118.2	117.6	115.8	114.6	116.7	114.7

4

5 **Table 5.F.7-4. Differences in Average Habitat Area (km^2) for *Potamocorbula* Recruitment in the Suisun**
6 **Bay and West Delta Subregions, by Water-Year Type and Modeling Scenario**

Water-Year Type	EBC1 vs. ESO_ELT	EBC1 vs. ESO_LLT	EBC2 vs. ESO_ELT	EBC2 vs. ESO_LLT	EBC2_ELT vs. ESO_ELT	EBC2_LLT vs. ESO_LLT
All	-8.3 (-8%)	-6.9 (-7%)	-1.4 (-1%)	0.1 (0%)	-1.5 (-2%)	-1.4 (-1%)
Wet	-14.0 (-15%)	-10.7 (-12%)	1.1 (1%)	4.4 (6%)	0.0 (0%)	0.8 (1%)
Above Normal	-16.3 (-16%)	-12.9 (-12%)	-1.1 (-1%)	2.3 (3%)	0.2 (0%)	0.4 (0%)
Below Normal	-4.0 (-4%)	-2.4 (-2%)	-4.3 (-4%)	-2.6 (-3%)	-3.2 (-3%)	-3.1 (-3%)
Dry	-2.8 (-3%)	-3.5 (-3%)	-2.7 (-2%)	-3.4 (-3%)	-2.9 (-3%)	-3.4 (-3%)
Critical	-2.1 (-2%)	-3.3 (-3%)	-1.6 (-1%)	-2.7 (-2%)	-2.4 (-2%)	-3.1 (-3%)
Note: Negative values indicate smaller average habitat area under ESO scenarios than EBC scenarios.						

7

8 **Table 5.F.7-5. Differences in Average Habitat Area (km^2) for *Potamocorbula* Recruitment in the Suisun**
9 **Bay and West Delta Subregions, by Water-Year Type and Modeling Scenario, with "No Fall X2" Project**
10 **Scenario (Alternative 1A)**

Water-Year Type	EBC1 vs. ALT1_ELT	EBC1 vs. ALT1_LLT	EBC2 vs. ALT1_ELT	EBC2 vs. ALT1_LLT	EBC2_ELT vs. ALT1_ELT	EBC2_LLT vs. ALT1_LLT
All	2.5 (2.4%)	0.9 (0.9%)	9.5 (9.8%)	7.9 (8.2%)	9.3 (9.6%)	6.4 (6.1%)
Wet	6.9 (7.4%)	8.2 (8.9%)	21.9 (28.2%)	23.3 (29.9%)	20.9 (26.4%)	19.7 (19.5%)
Above Normal	0.9 (0.9%)	-1.9 (-1.8%)	16.1 (18.4%)	13.3 (15.2%)	17.4 (20.1%)	11.4 (11.3%)
Below Normal	1.5 (1.5%)	-2.1 (-2.0%)	1.3 (1.2%)	-2.3 (-2.3%)	2.3 (2.3%)	-2.8 (-2.7%)
Dry	0.5 (0.4%)	-2.7 (-2.5%)	0.6 (0.5%)	-2.6 (-2.4%)	0.3 (0.3%)	-2.6 (-2.5%)
Critical	-1.2 (-1.1%)	-3.2 (-2.7%)	-0.7 (-0.6%)	-2.6 (-2.2%)	-1.5 (-1.3%)	-3.0 (-2.6%)
Note: Negative values indicate smaller average habitat area under project scenarios than EBC scenarios.						

11

1   ## 5.F.6.3.2   Aquatic Habitat Restoration (CM4, CM5, and CM6)

2   Aquatic habitat restoration actions are designed to increase the area, diversity, and connectivity of
3   habitats available to enhance food resources and support covered fish in the Delta. Restoration
4   areas are distributed across the Delta: the Sacramento River and northern Delta at Cache Slough, the
5   Cosumnes and Mokelumne Rivers in the eastern Delta, the San Joaquin River in the southern Delta,
6   the western Delta, and Suisun Marsh. Habitat types that could be colonized by mollusks include tidal
7   wetland (CM4) and channel margin (CM6), while inundated floodplains (CM5) could export
8   phytoplankton that is consumed by clams. (The expected habitat restoration is discussed further in
9   Appendix 5.E, *Habitat Restoration.*)

10 Aquatic restoration under BDCP will create new benthic habitat that may be colonized by
11 *Potamocorbula* or *Corbicula*, depending on the salinity regime. Physical and biological interactions
12 can enhance or constrain the success of restoration in meeting conservation goals (Lopez et al.
13 2006). Some physical features that favor invasive species could be controlled, such as water depth,
14 and location and dimension of levee breaks that determine residence time and circulation pathways
15 (Lopez et al. 2006). Biological processes, such as the extent of potential colonization, are frequently
16 indeterminate. If invasive clams become established, their vigorous filter feeding could take up an
17 indeterminate portion of the expected phytoplankton and microzooplankton. Invading clams likely
18 would constrain but not eradicate foodweb benefits, and adaptive management over time would
19 improve understanding and management of invasive clams in restored areas. The greater patchiness
20 in *Corbicula* distribution makes it more difficult to predict the extent of potential *Corbicula*
21 expansion and impact.

22 Because salinity is a significant factor in clam distribution, understanding the likely salinity regime
23 in different ROAs will guide evaluation of risk from clams. Suisun Bay is a stronghold of
24 *Potamocorbula*, but distributions within Suisun Marsh vary. *Potamocorbula* may be able to establish
25 in restored areas where salinities are greater than 5 ppt (e.g., Goodyear and lower Suisun Sloughs),
26 while other areas farther into the marsh (i.e., Denverton Slough) could continue to resist invasion
27 (O'Rear and Moyle 2008, 2009).

28 Moving eastward, at Chipps Island *Potamocorbula* were found consistently in the spring, regardless
29 of whether it was a drought year (e.g., 1988) or wet year (e.g., 1995) (California Department of
30 Water Resources 2001b). The extent of *Potamocorbula* in the fall months varies more substantially
31 and is dependent on Delta outflow. In the fall of 1995, a wet year, *Potamocorbula* populations moved
32 westerly in response to higher freshwater flows, to around Chipps Island (California Department of
33 Water Resources 2001b). In drier fall months, such as in 1990, *Potamocorbula* was detected in the
34 downstream reaches of the Sacramento and San Joaquin Rivers (Hymanson 1991). Downstream
35 reaches of the Sacramento and San Joaquin Rivers are most likely vulnerable to invasion from larval
36 recruits originating from the population in the Chipps Island channel. Recruitment from the Chipps
37 Island population occurs mostly in the fall months. In drier years, there is the risk of larval
38 *Potamocorbula* recruiting to upstream reaches.

39 The West Delta ROA appears to be the current upstream limit of *Potamocorbula* distribution. This
40 ROA may become vulnerable to *Potamocorbula* during dry years, when more easterly X2 allows
41 recruitment farther upstream. Upstream restorations areas planned at Cache Slough, the Yolo
42 Bypass, East Delta, and South Delta are well upstream of the salinity tolerance of *Potamocorbula,*
43 and therefore *Potamocorbula* is not likely to occur in those ROAs. As noted above, however,

1   *Corbicula* may invade restored areas too fresh for *Potamocorbula*. This includes Cache Slough, the
2   east Delta, and south Delta.

3   The relative effect of benthic grazing on phytoplankton may vary with habitat depth (Lucas et al.
4   1999; Lopez et al. 2006). As the water column becomes shallower, benthic filter feeders have greater
5   access to phytoplankton in the overlying water (Lucas et al. 1999). Lopez and others (2006)
6   evaluated the hypothesis that phytoplankton biomass, production, and pelagic energy flow vary
7   with habitat depth. They measured phytoplankton productivity, nutrients, tidal transport, and
8   *Corbicula* densities in a variety of "shallow" aquatic habitats (Franks Tract mean depth 2.5 meters,
9   Mildred Island mean depth 5 meters) and their adjacent deep channels, including Franks Tract and
10 Mildred Island. The habitat provided by these two flooded islands is deeper than much of the
11 shallow habitat expected under the Plan. Phytoplankton biomass and production were consistently
12 low in habitats colonized by *Corbicula*. Their grazing rates were, on average, eight times higher than
13 zooplankton grazing rates in those colonized habitats. Lopez and coauthers (2006) concluded that
14 fast transport and fast *Corbicula* grazing are the key processes leading to the decorrelation between
15 phytoplankton growth rate and biomass distribution. Phytoplankton biomass provides no
16 information about these governing processes, so biomass alone is a weak indicator of the ecological
17 value of aquatic habitats. Whereas shallow pelagic systems routinely functioned as net sources of
18 phytoplankton biomass, this trend was not true when accounting for losses to *Corbicula* grazing.
19 Despite higher phytoplankton growth rates in shallow habitats, consumption by *Corbicula* rendered
20 nearly all colonized shallow habitats phytoplankton sinks (Lopez et al. 2006). *Corbicula* distribution
21 was inexplicably patchy, which implies high uncertainty in the outcomes of creating new aquatic
22 habitat (Lucas et al. 2002).

5.F.6.3.3   CM20 Recreational Users Invasive Species Program

24 Under CM20, the Implementation Office will fund a Delta Recreational Users Invasive Species
25 Program designed to implement actions to prevent the introduction of new invasive species into the
26 Plan Area. Funding will be provided to implement the CDFW Watercraft Inspection Program and
27 reduce the spread of existing aquatic invasive species via recreational watercraft, trailers, and other
28 mobile recreational equipment used in aquatic environments in the Delta. It will do this primarily by
29 educating recreational users about the importance of avoiding further introductions of aquatic
30 invasive species and by instituting recreational watercraft inspections that directly reduce the risk
31 of invasive species introduction and proliferation.

32 A key component of an integrated aquatic invasives program is prevention, which incorporates
33 regulatory authority, risk analysis, knowledge of introduction pathways, and inspections. While no
34 feasible control measures are known for eradicating well-established invasive mollusks such as
35 *Corbicula* and *Potamocorbula,* prevention of further invasions is critical to avoid further stress to the
36 Delta ecosystem.

37 Two of the most invasive aquatic species known, zebra mussels and quagga mussels, have not yet
38 invaded the Delta. If these arrive, they likely would become established in more freshwater locations
39 (e.g., East Delta ROA, Cache Slough ROA) and would exacerbate the negative impacts already
40 imposed by *Potamocorbula* and *Corbicula*. These two dreissenid mussels could be introduced as
41 veligers persisting in boats transported from infested waters that retain moisture in live wells or
42 bilges, or as adults attached to boats and trailers (California Department of Fish and Game 2008). To
43 prevent transport, boats must be properly cleaned, drained, and dried after leaving a water body
44 that could harbor mussels or mussel larvae (California Department of Fish and Game 2008).

1 Controlling the introduction of additional invasive mollusks, or the further spread of any existing
2 nonnative mollusk species, would benefit aquatic natural communities in the Plan Area.

3 ## 5.F.6.3.4   Potential Direct and Indirect Effects on Covered Species

4 ### 5.F.6.3.4.1   Delta Smelt

5 *Potamocorbula* could invade portions of the restored areas and graze heavily on phytoplankton,
6 reducing the newly created food supply for calanoid copepods, a primary prey item of delta smelt
7 (Bennett 2005). *Potamocorbula* also contribute to increased water clarity, which negatively affects
8 delta smelt by reducing cover from predators and impairing feeding efficiency. Young delta smelt
9 are unable to feed efficiently unless particles are suspended in the water column (Baskerville-
10 Bridges et al. 2004).

11 The effects of *Corbicula* in lower-salinity (<2 ppt) regions of the Delta are expected to be similar to
12 those of *Potamocorbula*. This would tend to affect food resources for adult delta smelt during the
13 winter and spring when they migrate east into the Delta, and for larval delta smelt in spring and
14 summer before they are transported to the western Delta regions that typically have salinity greater
15 than 2 ppt. (See Appendix 5.E, *Habitat Restoration,* for a discussion of foodweb benefits of
16 restoration.)

17 ### 5.F.6.3.4.2   Longfin Smelt

18 Effects are similar to those for delta smelt, but not as severe because longfin smelt do not spend as
19 much time rearing in areas invaded by *Potamocorbula*, such as Suisun Bay, or by *Corbicula*, such as
20 the central Delta and Cache Slough. Rosenfield and Baxter (2007) identified a decline in the survival
21 of longfin smelt between Age-1 and Age-2 that may have resulted result from a decline in the
22 abundance of prey items following establishment of *Potamocorbula*. (See Appendix 5.E, *Habitat
23 Restoration,* for a discussion of foodweb benefits of restoration.)

24 ### 5.F.6.3.4.3   Steelhead and Chinook Salmon

25 Juvenile salmonids typically feed on zooplankton and insect larvae while in the Delta. Juvenile
26 Chinook salmon, for example, rely predominantly on chironomids (Williams 2010), with some
27 amphipods derived from littoral sources while in the Delta (Grimaldo et al. 2009b). The abundance
28 of zooplankton and aquatic insect larvae are highly dependent on the availability of phytoplankton
29 at the base of the aquatic foodweb. Because grazing rates of clams surpass the phytoplankton
30 growth rate, the foodweb benefits of tidal wetland restoration could be reduced if *Potamocorbula* or
31 *Corbicula* invade the restored areas. However, foodweb benefits derived from floodplain restoration
32 are not expected to be diminished; the risk of invasion in floodplain restoration areas is low because
33 of the seasonality of inundation. (See Appendix 5.E, *Habitat Restoration,* for a discussion of foodweb
34 benefits of restoration.)

35 ### 5.F.6.3.4.4   Sacramento Splittail

36 There is some indication that splittail are food-limited given that their growth rates declined
37 following the invasion of *Potamocorbula* and the collapse of *Neomysis,* due to high rates of
38 phytoplankton grazing by *Potamocorbula* (Feyrer et al. 2003). Splittail generally feed on benthic
39 invertebrates in areas of slower currents (Moyle 2002). Since the *Potamocorbula* introduction in
40 1986, clams have been a dominant food item in older splittail (Feyrer et al. 2003). Clams expanding

1   into restored areas could increase benthic food resources for splittail but would likely reduce
2   zooplankton resources. Splittail also are known to rear in tidal wetlands. Restored tidal wetlands are
3   intended to increase rearing habitat and improve food resources for splittail. However, restored
4   tidal wetlands also may be exploited by the opportunistic *Potamocorbula*, reducing the foodweb
5   benefits anticipated by the restoration actions. (See Appendix 5.E, *Habitat Restoration,* for a
6   discussion of foodweb benefits of restoration.)

5.F.6.3.4.5   Sturgeon

8   Introduced *Potamocorbula* and *Corbicula* are now the principal food of white sturgeon (Stewart et al.
9   2004; Israel et al. 2009). Israel and Klimley (2008) note that *Potamocorbula* has replaced native
10 mollusks and shrimp as food for green sturgeon. (See Appendix 5.E, *Habitat Restoration,* for a
11 discussion of foodweb benefits of restoration.)

5.F.6.3.4.6   Pacific Lamprey and River Lamprey

13 *Potamocorbula* and *Corbicula* have little or no effect on Pacific lamprey and river lamprey that
14 migrate through the Delta. Returning adults do not feed during their spawning migration. The diet of
15 macrophthalmia (the life stage that migrates from rivers to the ocean) is poorly understood, but it
16 seems unlikely that these jawless fishes consume hard-shelled mollusks. It is unclear whether
17 macrophthalmia feed on zooplankton that could be diminished by clam grazing. (See Appendix 5.E,
18 *Habitat Restoration,* for a discussion of foodweb benefits of restoration.)

5.F.6.4   Uncertainties and Research Needs

20 A variety of poorly understood factors influence whether an area actually is colonized by
21 *Potamocorbula.* A critical uncertainty is whether areas with high primary productivity (e.g., Suisun
22 Bay) can accumulate high phytoplankton biomass despite the presence of *Potamocorbula* (Surface
23 Water Ambient Monitoring Program 2010). Based on relationships between the introduction of
24 *Potamocorbula* and the accumulation of phytoplankton biomass, there has been the assumption that
25 the grazing effect of *Potamocorbula* limits the accumulation of phytoplankton biomass regardless of
26 the rate of primary production. However, in the 2010 Surface Water Ambient Monitoring Program
27 (SWAMP) study a bloom did occur when *Potamocorbula* were present and in the same
28 concentrations as previous years (Taberski et al. 2010).

29 As more fully discussed in Appendix 5.D, *Contaminants*, increased selenium uptake into the food
30 chain via invasive clams is not an anticipated result of covered activities. This conclusion is based
31 primarily on the finding that residence time of water in Suisun Bay will not increase with the BDCP,
32 and an increase in residence time would be critical for increased uptake of selenium by the clam
33 population. However, there is uncertainty associated with this conclusion because of the complexity
34 of factors that determine selenium biogeochemistry and bioavailability.

35 Factors in addition to bottom-up food limitation also contribute to recent declines in fishes of the
36 Delta (Baxter et al. 2010). High clam abundance and biomass is not unprecedented, and
37 phytoplankton and zooplankton declines preceded the declines in fish species. In addition, new
38 research shows that even though phytoplankton fuels the Delta foodweb, many of the zooplankton
39 species currently present in the estuary are omnivorous and can consume microbes utilizing
40 dissolved and particulate organic carbon from the detritus-based foodweb (Baxter et al. 2010).

1   Understanding the distribution patterns and foodweb dynamics of invasive mollusks has advanced
2   thanks to long-term monitoring of benthic invertebrates (e.g., California Department of Water
3   Resources 2001b; Peterson and Vayssieres 2010; O'Rear and Moyle 2008) and recent and ongoing
4   studies of foodweb dynamics and invasives, as synthesized by the workgroup for the pelagic
5   organism decline (POD) (Baxter et al. 2010).

6   Monitoring of the benthic community at existing and restored habitats will be critical to evaluate
7   trends in benthic community composition. DWR's Generalized Random Tessellation Stratified
8   (GRTS) study is an example of a design to monitor and analyze the Delta benthos. This 5-year
9   (2007–2011) study sampled benthos each May and October at 175 sites (50 fixed, 125 variable
10   sites) from San Pablo Bay to Stockton, and lower Cache Slough to CCF. GRTS data are being
11   evaluated (Gehrts pers. comm.).

12   Management in the face of invasive mollusks would benefit from further investigation of constraints
13   that limit transport, settlement, and establishment of larvae. Observed distribution of clams such as
14   *Corbicula* can be patchy (Lucas et al. 2002). Additional information is needed on clam tolerance for
15   low DO, clam feeding rates relative to water temperature, and how salinity and water temperature
16   covary.

17   The role of nutrients in facilitating *Potamocorbula* invasion also has been hypothesized (Glibert et al.
18   2011), but the mechanism of the potential relationship is unknown. Further research on
19   *Potamocorbula* responses to different nutrient variables is warranted. Nutrient variables could
20   include concentrations, forms (e.g., ammonium, inorganic and organic phosphorus), and ratios
21   (DIN:P). *Potamocorbula* response variables of interest could include metabolism (filtering and
22   consumption rates, e.g., Paganini et al. 2010), larval recruitment success, and comparison of
23   distribution patterns with nutrient measurements in the field.

24   Although *Potamocorbula* has successfully invaded the San Francisco Bay estuary, it is not yet
25   documented at other eastern Pacific Rim locations. Possible explanations include physiological
26   constraints in other locations, where *Potamocorbula* is not yet introduced or not yet detected.
27   Evaluation of conditions at uninvaded ports may be informative, particularly in regards to
28   developing control measures. At this time, management options are limited. One approach under
29   discussion is the manipulation of abiotic variables such as salinity to control clam distribution.
30   However, scientists debate the likely effectiveness of this approach. A key research need is to
31   identify mechanical and biological control strategies for established clams and prevention measures
32   for potential invaders.

5.F.6.5   Conclusions

34   **Water operations (*CM1 Water Facilities and Operation*) may affect the average amount of habitat**
35   **with salinity greater than 2 ppt compared to EBC2, depending on the outcome of the Fall X2**
36   **decision tree, thus potentially affecting suitable habitat for *Potamocorbula*.**

37   If Fall X2 is implemented, as is modeled in the ESO, no change in suitable habitat *Potamocorbula*
38   from water operations would occur. However, if Fall X2 is not implemented, X2 would occur more
39   easterly than under EBC2, and therefore the suitable habitat for *Potamocorbula recruitment* would
40   be expanded in wet and above normal years. Likewise, increased tidal habitat from *CM4 Tidal*
41   *Natural Communities Restoration* may facilitate recruitment and expansion of *Potamocorbula* if
42   located in areas with salinity greater than 2 ppt. If this occurs, the foodweb benefits described in
43   Appendix 5.E, *Habitat Restoration*, may be reduced.

1   Water operations that affect salinity gradients could affect the recruitment and distribution of
2   *Potamocorbula* in the brackish western Delta and *Corbicula* in freshwater habitats. Water operations
3   (*CM1 Water Facilities and Operation*) will be within a proposed decision-tree range. The ESO
4   includes the Fall X2 requirement. Operations under the ESO generally provided *Potamocorbula*
5   recruitment habitat suitability in the West Delta and Suisun Bay subregions similar to the EBC2
6   scenarios, reflecting the inclusion of the Fall X2 water management measure in CM1 during the main
7   *Potamocorbula* recruitment period. However, if Fall X2 standards are not implemented, operations
8   would comply with D-1641 Delta outflow requirements. In that situation, outflows in wet and above
9   normal years would be similar to conditions under Alternative 1A (ALT1_ELT and ALT1_LLT), in
10   which X2 is more easterly than under EBC2. This situation may allow for *Potamocorbula* to recruit
11   farther into the central Delta, and conversely reduce available habitat for *Corbicula*, which requires
12   more freshwater conditions (<2 ppt). These invasive clams have the potential to reduce food
13   production and export from the ROAs.

14   **Funding efforts that prevent the introduction of new invasive species (*CM20 Recreational Users**
15   **Invasive Species Program*) would benefit covered fish species in the Plan Area.**

16   A key component of an integrated aquatic invasives program is prevention, which incorporates
17   regulatory authority, risk analysis, knowledge of introduction pathways, and inspections.
18   Specifically, efforts that prevent the transport of invasive species by requiring recreational boats to
19   be properly cleaned, drained, and dried after leaving a water body that could harbor invasive
20   mollusk species are considered beneficial. Public outreach and education about transport,
21   introduction, and consequences of invasive aquatic species is another critical effort.

22   While no feasible control measures are known for eradicating well-established invasive mollusks
23   such as *Corbicula* and *Potamocorbula*, prevention of further invasions is critical to avoid further
24   stress to the Delta ecosystem.

25   5.F.7   *Microcystis*

26   5.F.7.1   Ecological Effect Pathways

27   5.F.7.1.1   Cyanobacteria *Microcystis*

28   *Microcystis* blooms were first observed in the Delta in 1999 (Lehman et al. 2005), and have been
29   associated with adverse effects on phytoplankton, zooplankton and fish populations in the Delta
30   (Baxter et al. 2010; Ger et al. 2010; Lehman et al. 2005, 2008, 2010; Teh et al. 2010; Acuña et al.
31   2012). Factors associated with *Microsystis* production include high water transparency, high water
32   temperature, low flow velocity and mixing, increased residence time, and high nutrient
33   concentrations (Chorus and Barrow 1999; Lehman et al. 2008; Mioni et al. 2012) (Table 5.F.8-1).

34   High nutrient concentrations and high nitrogen to phosphorus ratios have been implicated in
35   initiation of blooms in the Delta and in other estuaries (Lehman et al. 2008, Glibert et al. 2011) The
36   changes in nutrient concentrations in the Delta, particularly elevated ammonium (NH_4^+) levels, are
37   also thought to favor *Microcystis* (Glibert et al. 2011) and contribute to a decline in phytoplankton
38   (Jassby et al. 2002). *Microcystis* rapidly assimilates ammonium over nitrate, and *Microcystis*
39   outcompetes other phytoplankton species when ammonium is high (Lehman et al. 2010). In general,
40   the drivers behind cyanobacteria production are associated with land use, particularly runoff from

1   agricultural and urban systems that increases nutrient loading (such as nitrogen and phosphorus),
2   hydrologic changes that create a stable water column with very little mixing, and increases in water
3   temperature (Mioni and Payton 2010).

4   *Microcystis* can negatively affect the growth and production of zooplankton, either through
5   absorption of toxins within the water column or direct ingestion (as food) (Ger et al. 2010). The
6   toxic compounds can reduce zooplankton growth and survival rates, although the effects can vary by
7   species. Due to its concentration of polyunstaturated and unsaturated fatty acids, *Microcystis* has
8   low nutritional value for zooplankton and is a poor food source compared to other phytoplankton
9   (Lehman et al. 2010). Further, the large diameter of algal mats make ingestion difficult, can clog
10 feeding appendages, increase food rejection rate, and decrease forage efficiency.

11 Microcystins are hepatotoxins (liver toxins) that can promote tumors and result in liver damage in
12 humans and wildlife. Microcystin can enter fish passively during swimming and respiration, and
13 actively during food ingestion. The toxin can damage gills (due to high pH), which can increase
14 microcystin uptake, causing damage to other internal organs, such as the liver. Ingestion of
15 microcystin stresses fish by slowing protein synthesis, disrupting normal organ function, and
16 potentially leads to an osmoregulatory imbalance that causes increased water uptake, thereby
17 increasing ingestion of toxins. Acuña and coauthors (2012) found potential sub-lethal effects on
18 splittail (inhibition of protein synthesis, necrosis in some tissue) from limited exposure to
19 microcystin. At a population level, mortality and delayed hatching likely depress population growth.
20 Data suggest that the presence of *Microcystis* blooms could result in acute and chronic effects on fish
21 including increased mortality, reduced fecundity, reduced feeding; and habitat avoidance
22 (Interagency Ecological Program 2007).

23 **Table 5.F.8-1. Physical Habitat Factors Leading to Increased Abundance of *Microcystis***

Abiotic Conditions	Description
Temperature	Growth begins when temperatures exceed 20°C; maximum growth rate at 29 to 32°C in laboratory (Lehman et al. 2008). Temperature may be most important factor in driving growth rates (Mioni et al. 2012)
Nutrients	Microcystis outcompete other phytoplankton spp. when NH^{4+} is high (Lehman et al. 2010)
Flow	Low streamflow and high residence time necessary for slow-growing Microcystis to accumulate biomass (Lehman et al. 2008)
pH	High pH enhances Microcystis bloom, but not necessary to initiate growth (Lehman et al. 2008)

24

25   5.F.7.2   Conceptual Model and Hypotheses

26   5.F.7.2.1   Conceptual Model

27 The conceptual model for evaluating effects of *Microcystis* included consideration of abiotic factors
28 known to increase *Microcystis* production and biological responses to the toxic microcystin
29 produced by *Microcystis*. Increased water temperatures, longer residence times, more periods of low
30 freshwater flows, and greater water clarity are all factors known to increase the probability of
31 *Microcystis* blooms (Lehman et al. 2008, 2010). Increases in *Microcystis* have coincided with water
32 clarity increases in the Delta during the last several decades (Kimmerer 2004; Nobriga et al. 2008;

1 Schoellhamer 2011) and an upward trend in spring-summer mean water temperature in the
2 freshwater Delta between 1996 and 2005 (Jassby 2008). Numerous studies show that *Microcystis*
3 blooms produce adverse effects on phytoplankton, zooplankton and fish populations in the Delta
4 (Baxter et al. 2010; Ger et al. 2010; Lehman et al. 2005, 2008, 2010; Teh et al. 2010; Acuña et al.
5 2012).

6 Hypotheses for evaluation include:

7 ● Changes to water operations that reduce Delta outflow and increase residence times may
8   promote *Microcystis* blooms.

9 ● Climate warming may have a more important effect on water temperatures than reduced
10   outflows.

11 ● Restoration of shallow water habitats, which have lower flows, higher residence times, and
12   warmer waters, may increase *Microcystis*, offsetting some of the benefits of habitat restoration.

13 ● Turbidity levels in the Delta could be affected by successful removal of IAV. Clearing away IAV
14   infestations would increase flow velocities and increase turbidity, which would impede the
15   growth rate of *Microcystis*.

16 5.F.7.3 Potential Effects: Benefits and Risks

17 5.F.7.3.1 CM1 Water Facilities and Operation

18 Water temperature is considered the most important factor driving growth of *Microcystis* in the
19 Delta (Mioni et al. 2012). This is an important consideration during the peak *Microcystis* growing
20 season of June through November. Blooms peak in the freshwaters of the central Delta when
21 summer water temperatures reach 20 to 25°C (Lehman et al. 2008). Modeling by Mioni (2012)
22 showed that a temperature threshold of 20°C exists for the Delta, above which blooms suddenly
23 become more likely and intense. The likelihood of a bloom increased from 10% to 50% when
24 modeled water temperatures increased from 20°C to 25°C.

25 Climate warming, not water operations, will determine future water temperatures in the Delta. The
26 DSM2 model projected annual average water temperature increases as a result of climate warming
27 ranging from 0.32°C (0.6°F) to 0.54°C (1°F) for the ELT (2025). The simulated increase of water
28 temperatures for the ELT was generally uniform through the year but was somewhat different in the
29 different regions. For the LLT (2060), the average annual water temperature increases ranged from
30 0.91°C (1.6°F) to 1.57°C (2.8°F). The simulated warming of water temperatures for the LLT was
31 more variable through the year and was somewhat different in each region (Appendix 5.C, *Flow,*
32 *Passage, Salinity, and Turbidity*).

33 Less Sacramento River flow due to proposed new north Delta diversions could exacerbate blooms
34 by reducing summertime turbidity and Delta flows and by increasing water residence times.
35 *Microcystis* bloom formation depends on low freshwater flow, stratification, high water clarity, and
36 high water temperature (Lehman et al. 2005, 2008), all factors that point toward increased potential
37 for bloom formation with lower Sacramento River flow.

38 The effect of CM1 operations on residence time was compared for each subregion of the Delta
39 during the growing season of *Microcystis* (summer and fall) using estimates from the DSM2-PTM
40 model (Table 5.F.8-2, Table 5.F.8-3, and Table 5.F.8-4; see also Appendix 5.C, Section 5.C.5.4.4).

1   Studies in 2004 documented the highest observed chlorophyll a concentrations at stations in
2   shallow flooded islands (Mildred Island) and slow-moving river channels (San Joaquin River in East
3   Delta) (Lehman et al. 2008). Modeled residence times under ESO were greater than under the EBC
4   scenarios in most regions, particularly in Cache Slough during summer, and South Delta and East
5   Delta during fall (Table 5.F.8-3). In the summer months under ESO_LLT, average residence times
6   were greater than under EBC2_LLT in Cache Slough (18 days, 87%), West Delta (3 days, 14%), East
7   Delta (6 days, 26%) and South Delta (4 days, 51%) subregions; but summer residence time was less
8   in Suisun Marsh (23 days, 39%). In the fall months, conditions under ESO_LLT gave longer residence
9   times than EBC2_LLT in the North Delta (6 days, 13%), Cache Slough (9 days, 32%), East Delta (13
10   days, 39%), South Delta (27 days, 274%), and Suisun Marsh (15 days, 80%) subregions.

11   Under CM1 operations without a Fall X2 action, i.e., under the low-outflow scenario (LOS), residence
12   times during the fall would be relatively less in the East Delta and South Delta subregions compared
13   to the ESO, but would be relatively greater in the West Delta and the North Delta (Table 5.F.8-4),
14   because of less Delta outflow. When compared with EBC2_LLT, which includes Fall X2 requirements,
15   fall residence times under LOS_LLT are similar in the East Delta and South Delta subregions, and 9
16   days (32%) greater in the West Delta subregion.

17   **Table 5.F.8-2. Seasonal Average Residence Time (Days) of Water Flowing through the Delta during**
18   **Potential *Microcystis* Bloom Period**

Subregions	Season	Months	Average Residence Time (days)							
			EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT	LOS_ELT	LOS_LLT
North Delta	Summer	Jun–Aug	32	33	36	37	37	38	38	37
	Fall	Sep–Nov	48	48	49	49	54	56	57	61
Cache Slough	Summer	Jun–Aug	18	18	19	20	41	38	41	36
	Fall	Sep–Nov	28	30	30	29	43	38	44	45
West Delta	Summer	Jun–Aug	21	22	25	23	26	27	27	26
	Fall	Sep–Nov	25	25	25	27	28	30	34	35
East Delta	Summer	Jun–Aug	20	22	26	24	28	34	30	30
	Fall	Sep–Nov	15	27	28	32	41	48	34	34
South Delta	Summer	Jun–Aug	7	8	9	9	12	13	13	13
	Fall	Sep–Nov	5	8	8	10	30	37	9	10
Suisun Marsh	Summer	Jun–Aug	51	52	54	58	58	35	59	35
	Fall	Sep–Nov	17	18	19	19	49	34	56	39

19

1 **Table 5.F.8-3. Differences in Seasonal Average Residence Time (Days) of Water Flowing through the**
2 **Delta during Potential *Microcystis* Bloom Period, EBC vs. ESO Scenarios**

Subregions	Season	Months	Difference in Residence Time (days and % difference)					
			EBC1 vs. ESO_ELT	EBC1 vs. ESO_LLT	EBC2 vs. ESO_ELT	EBC2 vs. ESO_LLT	EBC2_ELT vs. ESO_ELT	EBC2_LLT vs. ESO_LLT
North Delta	Summer	Jun–Aug	5 (17%)	6 (19%)	4 (11%)	4 (12%)	1 (1%)	1 (3%)
	Fall	Sep–Nov	6 (12%)	8 (16%)	6 (13%)	8 (17%)	5 (11%)	6 (13%)
Cache Slough	Summer	Jun–Aug	23 (132%)	20 (116%)	23 (122%)	20 (107%)	22 (111%)	18 (87%)
	Fall	Sep–Nov	14 (50%)	10 (34%)	12 (40%)	8 (25%)	12 (40%)	9 (32%)
West Delta	Summer	Jun–Aug	5 (25%)	6 (27%)	4 (19%)	5 (20%)	2 (8%)	3 (14%)
	Fall	Sep–Nov	3 (14%)	5 (21%)	3 (13%)	5 (21%)	3 (11%)	3 (11%)
East Delta	Summer	Jun–Aug	8 (39%)	10 (49%)	7 (31%)	9 (40%)	2 (9%)	6 (26%)
	Fall	Sep–Nov	27 (179%)	30 (203%)	14 (54%)	18 (67%)	14 (50%)	13 (39%)
South Delta	Summer	Jun–Aug	5 (71%)	6 (84%)	5 (62%)	6 (74%)	3 (34%)	4 (51%)
	Fall	Sep–Nov	26 (534%)	32 (662%)	22 (271%)	28 (346%)	23 (287%)	27 (274%)
Suisun Marsh	Summer	Jun–Aug	7 (13%)	-16 (-31%)	6 (12%)	-16 (-32%)	4 (7%)	-23 (-39%)
	Fall	Sep–Nov	33 (198%)	17 (104%)	31 (172%)	16 (87%)	31 (163%)	15 (80%)

3

4 **Table 5.F.8-4. Differences in Seasonal Average Residence Time (Days) of Water Flowing through the**
5 **Delta during Potential *Microcystis* Bloom Period between, EBC vs. LOS Scenarios**

Subregions	Season	Months	Difference in Residence Time (days and % difference)					
			EBC1 vs. LOS_ELT	EBC1 vs. LOS _LLT	EBC2 vs. LOS _ELT	EBC2 vs. LOS _LLT	EBC2_ELT vs. LOS _ELT	EBC2_LLT vs. LOS _LLT
North Delta	Summer	Jun–Aug	7 (21%)	5 (16%)	5 (14%)	3 (9%)	2 (5%)	0 (0%)
	Fall	Sep–Nov	10 (20%)	13 (28%)	10 (21%)	13 (28%)	9 (19%)	12 (24%)
Cache Slough	Summer	Jun–Aug	24 (136%)	18 (103%)	23 (125%)	17 (94%)	22 (114%)	15 (75%)
	Fall	Sep–Nov	16 (56%)	17 (59%)	14 (46%)	15 (48%)	14 (45%)	16 (56%)
West Delta	Summer	Jun–Aug	6 (30%)	5 (23%)	5 (23%)	4 (17%)	3 (12%)	3 (11%)
	Fall	Sep–Nov	10 (39%)	11 (43%)	10 (38%)	11 (43%)	9 (36%)	9 (32%)
East Delta	Summer	Jun–Aug	9 (45%)	10 (48%)	8 (37%)	9 (39%)	4 (14%)	6 (25%)
	Fall	Sep–Nov	19 (131%)	19 (128%)	7 (27%)	7 (25%)	7 (24%)	1 (4%)
South Delta	Summer	Jun–Aug	5 (74%)	6 (82%)	5 (65%)	6 (73%)	3 (37%)	4 (50%)
	Fall	Sep–Nov	5 (96%)	5 (101%)	1 (15%)	1 (18%)	2 (19%)	0 (-1%)
Suisun Marsh	Summer	Jun–Aug	7 (15%)	-16 (-32%)	7 (14%)	-17 (-32%)	5 (8%)	-23 (-40%)
	Fall	Sep–Nov	39 (237%)	22 (133%)	38 (208%)	20 (113%)	37 (197%)	20 (106%)

6

7 5.F.7.3.2   Aquatic Habitat Restoration (CM2, CM4, CM5, and CM6)

8   Habitat restoration actions may create more slow-flowing, warmer water areas, with less mixing
9   within the Delta that may encourage *Microcystis* growth. *Microcystis* blooms in restored aquatic
10 habitats would offset some of the benefits of habitat restoration by reducing zooplankton
11 production, fish food quality and fish feeding success.

1   ### 5.F.7.3.3   Submerged Aquatic Vegetation Control (CM13 Invasive
2   Aquatic Vegetation Control)

3   **SAV control may locally increase water turbidity and flow velocity in treated areas, discouraging**
4   ***Microcystis* growth. Herbicides could locally reduce the distribution of *Microcystis* if it is vulnerable to**
5   **herbicides used.**

6   Recent surveys in the Delta have shown that low water velocity and high water temperature were
7   strongly correlated with the seasonal variation of *Microcystis* cell density (Lehman et al. 2008). IAV
8   control may increase turbidity and flow velocity, particularly in restored aquatic habitats, which
9   could discourage *Microcystis* growth in these areas. The changes in nutrient concentrations in the
10   Delta, particularly elevated ammonium levels, that are thought to lead to conditions favorable to IAV
11   (Feijoó et al. 2002) also are thought to favor *Microcystis* (Glibert et al. 2011) and contribute to a
12   decline in phytoplankton (Jassby et al. 2002). An additional consideration is that the high
13   photosynthetic activity in dense SAV stands leads to high pH, which *Microcystis* is more tolerant of
14   than is phytoplankton. Removal of SAV may alleviate high pH conditions that favor *Microcystis*. Thus,
15   to the extent that IAV removal would affect turbidity, water velocity, nutrient ratios, and water
16   temperatures, it seems possible that IAV removal would not have led to an increase in *Microcystis*
17   and could help reduce blooms in the future.

18   Herbicides could locally reduce the distribution of *Microcystis* if it is vulnerable to herbicides used.
19   For example, application of diquat is particularly effective at inhibiting or eliminating *Microcystis*
20   (Emmett 2002), although DBW now avoids using diquat when smelt or juvenile salmon are present
21   (Section 5.F.4.3.1.2, *Potential Risks and/or Detrimental Effects*). Uncertainty remains regarding the
22   effects of herbicide treatments to control IAV and the relationship to phytoplankton and *Microcystis*
23   abundances. SAV removal could affect *Microcystis* blooms primarily in three ways.

24   ● The relative toxicities of the herbicides to phytoplankton and *Microcystis* could affect the
25   relationship between the two.

26   ● The decay of large amounts of dead SAV/FAV has a short-term effect on water quality and
27   nutrient balance.

28   ● In the long term, the effect of SAV removal could affect *Microcystis* through its effects on changes
29   in water quality, particularly nutrient loads and ratios.

30   Fluridone is currently the preferred herbicide used in the Delta to control *Egeria*. Experimental
31   results are somewhat mixed regarding fluridone's effects on phytoplankton. Several early studies
32   showed that phytoplankton were unaffected by fluridone treatment, whereas others showed toxic
33   effects on both phytoplankton and blue-green algae (reviewed in Struve et al. 1991). However, it
34   appears that fluridone applied at the concentrations used in the Delta (typically 10 to 50 parts per
35   billion) does not have an adverse effect on phytoplankton and blue-green algae or affect the
36   phytoplankton community structure. Additionally, application of fluridone would kill SAV at a slow
37   pace, reducing the likelihood that the death and decay of SAV would release substantial levels of
38   nutrients to facilitate *Microcystis* blooms.

1   ## 5.F.7.3.4   Potential Direct and Indirect Effects on Covered Species

2   ### 5.F.7.3.4.1   Delta Smelt

3   Delta smelt spawn in freshwater portions of the Delta in the spring and rear in the Suisun Bay and
4   Suisun Marsh from spring to early fall, and thus may be exposed to *Microcystis* for part of its
5   lifecycle. As such, delta smelt may experience the physical effects of exposure to microcystin, which
6   could decrease overall fitness and potentially reduce growth and survival. Since delta smelt
7   distribution is correlated with location of X2, project actions that bring X2 closer to areas that favor
8   *Microcystis* production in the late summer and early fall may have negative effects, either through
9   direct exposure to toxins or reduced food availability. Microcystin has toxic effects on two copepod
10   prey species of delta smelt, *Eurytemora affinis* and *Pseudodiaptomous forbesi* (Ger et al. 2010).

11   ### 5.F.7.3.4.2   Longfin Smelt

12   Longfin smelt spawn in the Delta from February through April, with embryos hatching within
13   40 days, then moving quickly into Suisun and San Pablo bays to rear. Their exposure to *Microcystis* is
14   likely limited by their life history, but similar to other Delta fish (and organisms at higher trophic
15   levels), longfin smelt may be affected if food resources are reduced in abundance or shift to less
16   palatable species.

17   ### 5.F.7.3.4.3   Steelhead and Chinook Salmon

18   Juvenile Chinook salmon and steelhead may not be directly exposed to blooms as they migrate
19   downstream as juveniles in late-spring to early summer. *Microcystis* blooms occur from June to
20   November, with peaks in September (Acuña et al. 2012). While there may be some overlap in
21   exposure, juveniles will likely avoid areas of high toxicity and move toward more favorable areas.
22   Juveniles rearing in the Delta feed on zooplankton, the species distribution and abundance of which
23   may be affected by *Microcystis* (Lehman et al. 2010). If zooplankton species distribution shifts
24   toward less palatable or nutritious species, or overall abundance of zooplankton decreases, then the
25   health and fitness of juvenile salmonids may also decrease.

26   ### 5.F.7.3.4.4   Sacramento Splittail

27   Sacramento splittail forage and spawn on flooded areas from late-winter to spring (Moyle et al.
28   2004). Juveniles remain until floodplains drain in late-spring then disperse to brackish tidal sloughs,
29   such as those found in Suisun Marsh. While the temporal distribution of splittail may not coincide
30   directly with *Microcystis* occurrence, exposure may still occur. Splittail are benthic foragers, feeding
31   on shrimp, amphipods, copepods, and phytoplankton detritus (Moyle et al. 2004). The fish can
32   potentially consume microcystins by directly feeding on *Microcystis*, which forms dense mats on the
33   water surface during the day, but drifts downward to the bottom at night (Acuña et al. 2012). Acuña
34   and coauthors (2012) found potential sub-lethal effects on splittail (inhibition of protein synthesis,
35   necrosis in some tissue) from limited exposure to microcystin, suggesting long-term exposure may
36   have substantial health effects.

37   ### 5.F.7.3.4.5   Sturgeon

38   Sturgeon are benthic feeders, thus they would likely experience similar effects as splittail (see Acuña
39   et al. 2012).

1 ### 5.F.7.3.4.6   Pacific Lamprey and River Lamprey

2 Lamprey feed on a variety of fish species. Microcystins can bioaccumulate in the tissue of prey fish
3 creating an exposure pathway for predator species such as lamprey. However, the effects of
4 microcystins toxicity on lamprey are currently unknown.

5 # 5.F.7.4   Uncertainties and Research Needs

6 There is the possibility that increasing water temperature is the key driver of increasing *Microcystis*
7 blooms, in which case blooms would become more prevalent in the future because of climate
8 change. Therefore, research is needed to establish which abiotic factors are most effective at
9 controlling *Microcystis* abundance and whether those factors feasibly can be managed. Studies also
10 should be conducted to determine whether restored habitats facilitate *Microcystis* blooms and
11 whether such blooms offset the potential foodweb benefits from habitat restoration.

12 Additionally. there is uncertainty regarding the effect of changing flow operations in the Delta (CM1)
13 on the proliferation of *Microcystis* blooms. Uncertainty exists pertaining to:

14 ● How changes in Delta outflow, particularly changes to address Fall X2 requirements, would
15   affect residence times and hence *Microcystis* growth.

16 ● Whether operations of proposed north Delta intakes would substantially alter Delta hydrology
17   in ways that would facilitate *Microcystis* growth.

18 ● Whether increases in water temperature due to climate change would overshadow changes in
19   flow dynamics under CM1.

20 ● How operations under CM1 may affect concentrations and ratios of nitrogen and phosphorus,
21   and whether this affects the likelihood and intensity of *Microcystis* blooms and microcystin
22   production.

23 ● How changes in the turbidity may affect the rate of toxic microcystin production by *Microcystis*.

24 Uncertainties associated with habitat restoration activities (*CM2 Yolo Bypass Fisheries Enhancement,*
25 *CM4 Tidal Natural Communities Restoration, CM5 Seasonally Inundated Floodplain Restoration, and*
26 *CM6 Channel Margin Enhancement*) revolve around the extent that restored areas create conditions
27 conducive to *Microcystis* blooms. Potential occurrence of *Microcystis* blooms in these areas would
28 partially offset the food production benefits of restored habitats.

29 There is uncertainty about the extent to which IAV removal techniques would affect *Microcystis*
30 abundances (*CM13 Invasive Aquatic Vegetation Control*). Removal of IAV may increase water
31 velocities and reduce water transparency, inhibiting the photosynthetic activities of cyanobacteria.
32 Application of herbicides to remove IAV can also have the ancillary effect of inhibiting *Microcystis*,
33 but results depend on the type and concentration of herbicide employed.

5.F.7.5   Conclusions

Changes to water operations (CM1) and specific restoration actions (*CM4 Tidal Natural Communities Restoration*) that reduce flows and increase water residence times in the Delta may facilitate blooms of *Microcystis,* reducing the quantity and quality of the food supply and increasing toxic exposure of covered fish species to microcystins.

Microcystis blooms are facilitated by warmer temperatures, low freshwater flows, and high residence time, among other factors. Water operations (CM1) would be dependent on the outcome of the decision trees for spring and fall outflow. Implementation of the ESO scenario would generally increase residence times throughout the Delta, whether or not Fall X2 requirements are implemented. Increased residence times facilitate *Microcystis* by allowing the population to proliferate and accumulate into blooms.

In addition to residence times, warmer water temperatures are a major driver of *Microcystis* blooms. Warmer water temperatures are expected to occur regionally as a result of climate change, and could occur locally as a result of tidal wetland restoration. Thus, higher water temperatures may have a greater effect on the potential for *Microcystis* blooms than changes associated with changed water operations under CM1.

An accumulation of *Microcystis* could offset some of the foodweb benefits of restoration by reducing zooplankton production, fish food quality, and fish feeding success and by increasing exposure of covered fish to toxins (microcystins).

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5.F.8.2   Personal Communications

Cavallo, Brad. Senior scientist. Cramer Fish Sciences, Auburn, CA. June 21 and 28, 2012—phone conversation with Ramona Swenson, Cardno ENTRIX, and email communication regarding fish removal techniques and experiments such as electrofishing (Cavallo et al. 2012), targeted predator fishing tournament, and orally delivered piscicide.

Gehrts, Karen. California Department of Water Resources, Sacramento, CA. February 21, 2012—personal communication with Ramona Swenson, Ph.D. Senior consultant/aquatic ecologist. Cardno ENTRIX, Sacramento, CA.

Nobriga, M. L. Fish Habitat Biologist. U.S. Fish and Wildlife Service, Sacramento, CA. May 23 and June 7, 2012—email to Chris Earle, ICF International, and phone conversation with Ramona Swenson, Cardno ENTRIX, Sacramento, CA, regarding foodweb interactions in Delta fish community, potential for predator effects, and recommendations for revising CM15.

Reeves, R. California Department of Water Resources, Sacramento, CA. August 27, 2012—Telephone conversation with Daniel Huang, Cardno ENTRIX, Sacramento, CA.